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FINAL REPORT

FEASIBILITY STUDY OF A CENTRIFUGE EXPERIMENT FOR THE APOLLO APPLICATIONS PROGRAM

VOLUME II

SPECIFICATION AND TEST REQUIREMENTS SPACE RESEARCH CENTRIFUGE ENGINEERING DEVELOPMENT PROTOTYPE

GENERAL DYNAMICS
Convair Division

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FEASIBILITY STUDY OF A CENTRIFUGE EXPERIMENT FOR THE APOLLO APPLICATIONS PROGRAM

VOLUME II

SPECIFICATION AND TEST REQUIREMENTS - SPACE RESEARCH CENTRIFUGE ENGINEERING DEVELOPMENT PROTOTYPE

Prepared under Contract NAS1-7309

by

CONVAIR DIVISION OF GENERAL DYNAMICS

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER

FOREWORD

This document is a compilation of general, subsystem and test specifications for the Space Research Centrifuge engineering development prototype. It comprises a portion of the final report prepared under Contract NAS1-7309, Feasibility Study of a Centrifuge Experiment for the Apollo Applications Program. Work was performed under the cognizance of Mr. G. Hausch, NASA LRC Technical Monitor for Contract NAS1-7309 and at the direction of Mr. J. E. Stumm, Convair program manager for the centrifuge study. Technical direction in the areas of experiment design and requirements was the responsibility of Dr. B. D. Newsom of Convair. The full report consists of the following:

Volume I	NASA CR-66649 (GDC-DCL-68-001)	Space Research Centrifuge Configuration, Installation and Feasibility Studies.
Volume II	NASA CR-66650 (GDC-DCL-68-002)	Specification and Test Requirements - Space Research Centrifuge Engineering Development Prototype.
Volume III	NASA CR-66651 (GDC-DCL-68-003)	Experimental Requirements for the Space Research Centrifuge
Volume IV	(GDC-DCL-68-004)	Manned Centrifuge Test Report.

Security classification approved per requirements of Paragraph 10, DOD 5520.22-M.

J. E. Stumm
Program Manager
Centrifuge Study

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SRC-SD-111

SYSTEM SPECIFICATION

For a

SPACE RESEARCH CENTRIFUGE

ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract No. NAS-1-7309

Prepared by

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1.0 SCOPE

This specification establishes the system level requirements for the detail design and fabrication of a ground based prototype of an orbital space research centrifuge to support the T-010 series of experiments proposed for the Apollo Applications Program.

1.1 DEFINITION

For the purpose of this specification, the "Ground Based Centrifuge System" is comprised of the following elements.

1. Space Research Centrifuge
2. Command and Control System
3. Support Frame & Perturbation System
4. Support Systems
5. Facility Requirements

1.1.1 Documents

The following documents form a part of this specification. (Ref. Fig. 1)

1. General Arrangement Drawing, SRC-SD-110
2. Support Frame & Perturbation System, SRC-SD-109
3. Drive Hub & Sensor System, SRC-SD-407
4. Primary Drive System, SRC-SD-409
5. Counterbalance System, SRC-SD-411
6. Translation System, SRC-SD-413
7. Pivot Drive System, SRC-SD-415
8. Roll Drive System, SRC-SD-417
9. Subject Couch System, SRC-SD-506
10. Instrumentation System, SRC-SD-202
11. Test Requirements Document, SRC-SD-604

1.2 PURPOSE

The ground based centrifuge system will be utilized, initially, to develop mechanisms and control systems, and to verify the performance capabilities of prototype hardware to insure the cost effectiveness of the orbital centrifuge hardware program.

1.2.1 Secondarily, the ground based centrifuge will be developed into a man-rated test facility to evaluate physical tolerances, training requirements, and man/machine integration during the T-010 experiment definition phase.

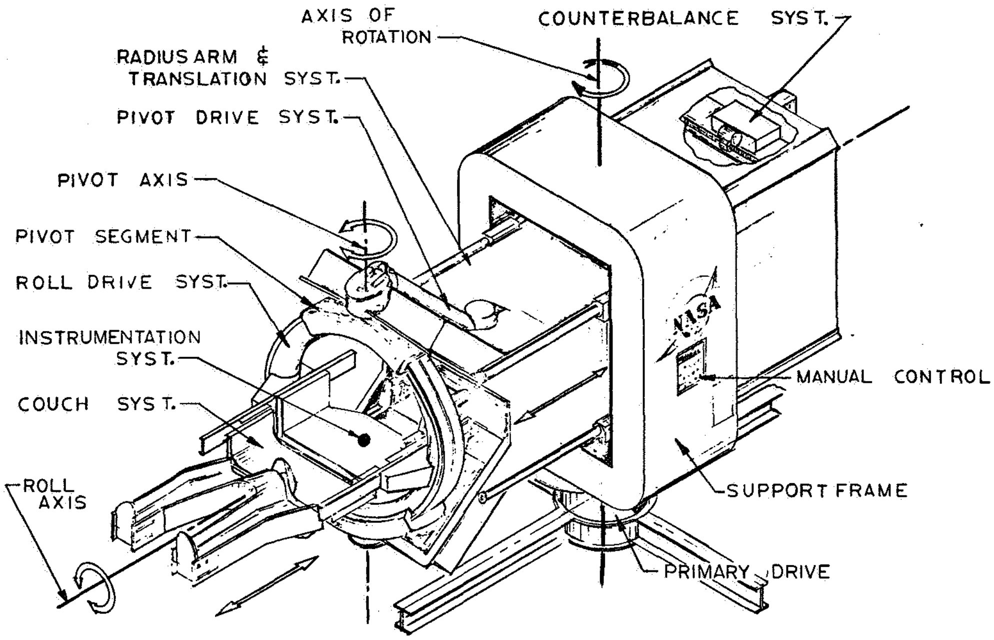

Figure 1. Ground Based Centrifuge

1.3 DESIGN DEVELOPMENT AND FABRICATION PHILOSOPHY

1.3.1 Preliminary design studies, supporting this specification, have defined three major development areas which require further definition and verification during the detailed design phase.

1.3.1.1 Bearing Technology

Orbital centrifuge environmental conditions dictate that the most desirable bearing system exhibit the following characteristics.

1. Light Weight
2. Dry Operation
3. Zero Noise
4. Moderate Life
5. No Contamination Generation

1.3.1.2 Electric Drive Technology

Analysis of the centrifuge motion requirements has defined three characteristic motor performance patterns.

1. Slow speed - low torque - wide-range - proportional control (Roll Drive)

2. Low torque - quick response - constant high speed (Translation & Counterweight Drives).

3. High torque - wide-range - proportional control - quick response (Primary Drive).

In all cases, spark-free (brushless), light weight and highly reliable units are required.

1.3.1.3 Specialized Gear Systems

Gear box design for the centrifuge drive systems will, for most applications, be highly precision sealed units which can be provided with conventional state of the art lubrication. The roll drive and primary drive, however, involve exposed gearing and are not compatible with the sealed unit concept. Development of suitable gear and material designs with the following characteristics is therefore desirable.

1. Dry Operation
2. Low Noise Level
3. Zero backlash
4. Moderate Life
5. No Contamination Generation
6. Light Weight

1.3.2 Fabrication Philosophy

The ground based centrifuge, objectively, is a test tool which must support both the final proofing of man-rated spacecraft hardware, and the baseline physiological testing required to finalize the T-010 experiment program. The earliest possible activation of the ground based system as a test bed to evaluate early hardware development is therefore to be emphasized. Since some of the space oriented hardware development will involve long lead times, and may not be completely compatible with a 1 "g" earth environment without special handling, it shall be necessary to utilize existing "off the shelf" hardware to the maximum extent possible. By taking this approach, many of the early development test objectives may be accomplished effectively without special test fixtures. Periodic updating of the baseline configuration to incorporate the developed hardware shall be integrated into a detailed program plan. This will enable a smooth transition from the baseline configuration to the man-rated orbital configuration and permit concurrent development of the T-010 experiment program to insure ultimate compatibility between man and machine.

2.0 FUNCTIONAL REQUIREMENTS

The ground based centrifuge shall be designed to provide the following capabilities.

1. One man occupancy.
2. Rotational rates sufficient to create a centrifugal force field equivalent to 9g units at the maximum radius of the astronaut couch.
3. An adjustable radius arm system shall be provided which will enable placement of the subject's head on the spin axis.
4. The system shall have sufficient degrees of freedom to permit rotation of the subject about a pivot axis, at the end radius arm, while the centrifuge is rotating.
5. Rotation of the test subject about his long body axis shall be provided.
6. A couch system with suitable adjustments to accommodate subject size variation between 25 and 75 percentile shall be provided.
7. The couch system shall permit articulation of the subject's legs and head with suitable restraints to limit these movements when desired.
8. Subject orientation, both in the plane of spin and normal to the plane of spin shall be provided by an alternate mounting capability. (Ref. Drawing SRC-SD-110, 3)

   All sub-systems shall be capable of operation in both of the mounting configurations, except automatic operation of the counterweight system shall not be required in the normal to the spin plane configuration.
9. The centrifuge shall be sized to meet all system requirements while enclosed in a chamber not to exceed 18 ft. in diameter and a height of 15 ft.

2.1 SUB-SYSTEM REQUIREMENTS

The baseline centrifuge system has been divided into the following functional sub-systems. The sub-systems shall be designed to meet the following baseline requirements when integrated with the centrifuge system.

2.1.1 Primary Rotational Sub-system

The primary rotational drive sub-system consists of a 3-phase AC type induction motor with a variable frequency, variable voltage speed controller and integral transmisssion system to support the following requirements. (Ref. Sub-system Drawing SRC-SD-409)

2.1.1.1 Drive operation shall be controlled by either on/off manual controls, or by a preprogrammed digitized tape through a function generator.

2.1.1.2 The drive and its control system shall be capable of simulating the "g" environment of Apollo re-entry.

2.1.1.3 The variable speed drive unit shall have a controlled deceleration device and a failsafe, positive acting, mechanical braking system.

2.1.1.4 Overspeed control shall be provided.

2.1.2 Radius Arm Translation Sub-System

System comprises a 3 phase AC motor driving a ball screw mechanism through a harmonic drive unit.

2.1.2.1 Controls for the translation drive are to be manually operated on/off type.

2.1.2.2 The sub-system shall have an automatic overtravel stop.

2.1.2.3 Each position of the radius arm shall be provided with a fail-safe mechanical locking device to prevent unintentional operation.

2.1.2.4 Operation of the translation drive is interlocked with the pivot frame position.

2.1.3 Couch Pivot Sub-system

The pivot drive is composed of a system of gearing and torque shafting which transmit the necessary torque from the 3-phase, AC drive motor unit to position and maintain the selected couch pivot orientation.

2.1.3.1 The subject couch shall be capable of plus or minus 100° rotation in either direction from the radius arm pivot axis.

2.1.3.2 Both manual and remotely operated automatic controls shall be provided for the system.

2.1.3.3 The system shall be provided with failsafe interlocking devices to prevent inadvertent operation.

2.1.4 Couch Roll Sub-system

Rotation of the couch roll frame within the pivot segments shall be provided by a close coupled, battery powered, DC drive unit mounted on the pivot frame.

2.1.4.1 Manual positioning of the subject couch to 0°, 45° and 90°, with respect to the pivot axis, shall be provided.

2.1.4.2 Fixed couch position shall be maintained by a failsafe, positive locking, mechanical locking system.

2.1.4.3 The couch roll system, when not in the locked position mode, shall have a variable speed control capable of responding to acceleration commands from $.1^\circ/sec^2$ to $3.0^\circ/sec^2$ up to 20 rpm.

2.1.4.4 A system of interlocks shall be provided to prevent inadvertent operation.

2.1.5 Couch Sub-system

A couch system consisting of a structural frame, contoured body supports, position and restraint mechanisms, a position monitoring system, and the interface connections and supports for the instrumentation sub-system shall be developed.

2.1.5.1 Provision shall be made to enable placement of a test subject's head either on the centrifuge spin axis or on the pivot axis.

2.1.5.2 A restraint system about the subject's head shall be adjustable to permit either free head movement, no head movement, or movement in one plane at a time. Position feedback of head movements is required.

2.1.6 Instrumentation and Control Sub-system

Initial design and development of the instrumentation and control sub-system shall be oriented toward three basic requirements.

2.1.6.1 Operating and Status

A system of command controls and position-status feedback data which will provide only the minimal control capability required to operate the centrifuge in support of the T-010 experiments shall be developed.

2.1.6.2 System Performance

A secondary system of control and feedback shall be developed which will include an override capability and direct instrumentation readout sufficient to enable system performance evaluation and trouble shooting.

2.1.6.3 Bio-Monitoring

A separate system of instrumentation shall be developed to provide the monitoring data necessary to evaluate test subject response and safety. The system shall include TV coverage of the test subject, two-way voice communication and a direct readout of critical medical measurements. Compatibility with IMBLM systems is required.

2.1.7 Drive Hub and Sensor Sub-system

Static balance of the centrifuge during varying modes of operation shall be maintained. A system of sensors at the drive hub shall provide a continuous readout of unbalanced conditions in excess of 10 lbs.

2.1.8 Counterbalance Sub-system

A counterbalancing system of translating weights, which can be driven automaticaly as a function of an unbalance signal from the sensor system, shall be provided. Response of the counterweight system shall be sufficient to counteract any unbalance resulting from subject articulation during a test run without affecting the test data or imposing excessive loads on the drive system.

3.0 PERFORMANCE

The performance requirements set forth in this specification are aligned to the presently defined T-010 group of experiments initially proposed for the Apollo Applications Program.

Final definition of the T-010 group of experiments is, to an extent, dependent upon the utilization of the ground based centrifuge as a tool for experiment development.

It shall be a design goal, therefore, to provide in the ground based centrifuge the highest possible level of performance flexibility commensurate with subject safety, weight, cost and state of the art availability.

3.1 PERFORMANCE REQUIREMENTS

The following T-010 experiments have been developed sufficiently to provide a baseline of performance parameters which establish the ground based centrifuge baseline requirements. (Ref: Vol. IV of this report).

3.1.1 T-010A Grayout Sensitivity Thresholds

Primary Rotation	-	47 rpm
Acceleration (max.)	-	.08 Rad/Sec^2
Radius Arm Setting	-	36 in.
Pivot Setting	-	0^o
Roll Setting	-	90^o
Couch Setting	-	0 in.
Subject C. G.	-	63 in.
Deceleration to Stop	-	20 sec.

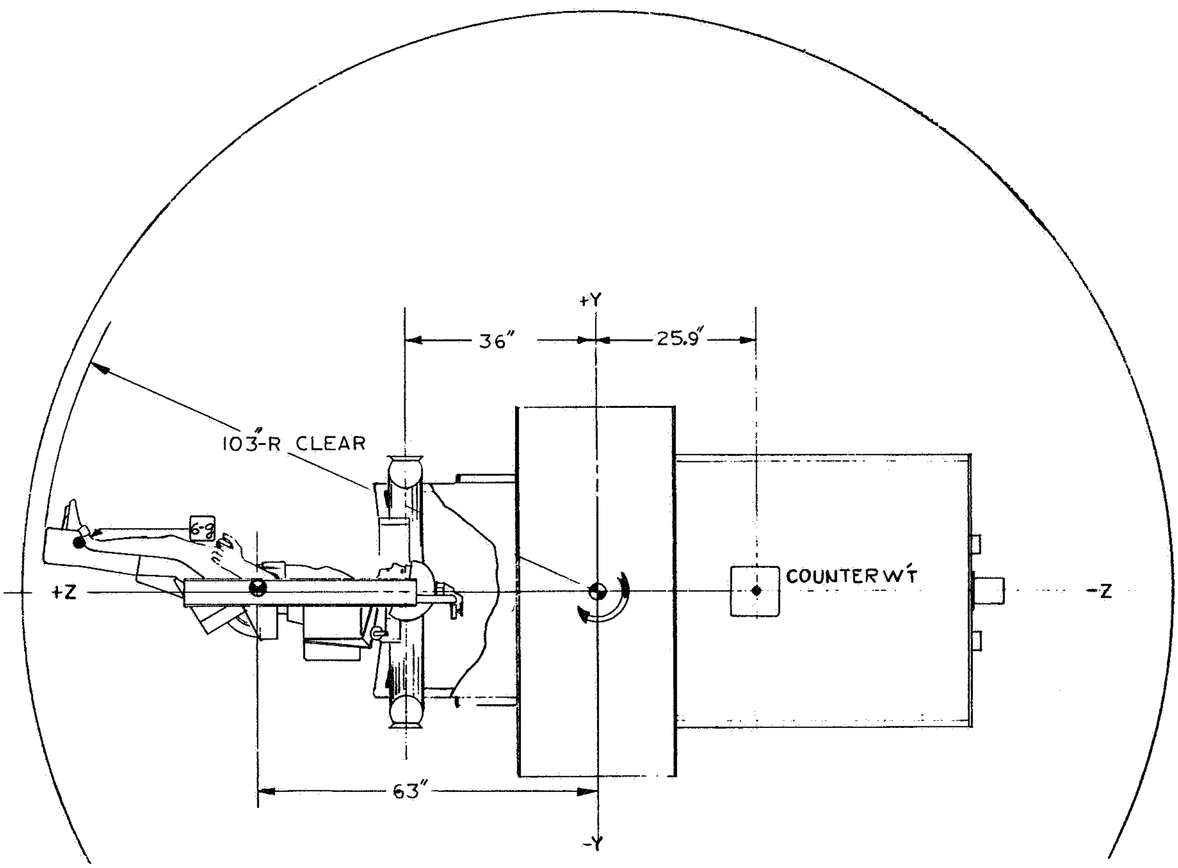

Figure 2. T-010A, Grayout Sensitivity Thresholds

3.1.2 T-010B - Therapeutic

Primary Rotation	-	53 rpm
Acceleration (max.)	-	.138 Rad/Sec^2
Radius Arm Setting	-	27 in.
Pivot Setting	-	0^o
Roll Setting	-	90^o
Couch Setting	-	11 in. (Legs up)
Subject C. G.	-	43 in.
Deceleration to Stop	-	20 sec.

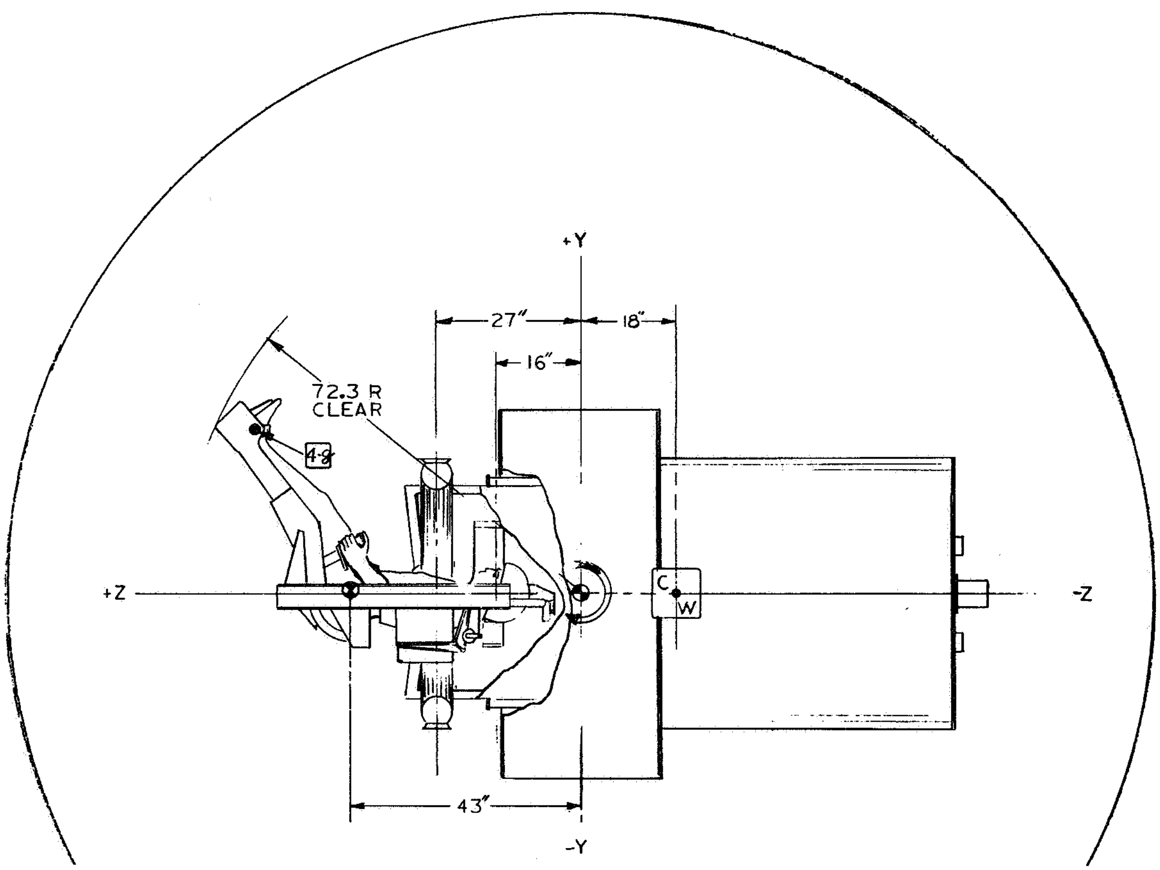

Figure 3. T-010B, Therapeutic

3.1.3 T-010C - Angular Acceleration Sensitivity Thresholds

Primary Rotation	-	Fixed
Pivot Setting	-	0
Roll Drive (max.)	-	20 rpm
Accelerations (variable)	-	0.1 to 3.0^{o}/Sec^{2}
Radius Arm Setting	-	54 in.
Couch Setting	-	27 in.
Subject C.G.	-	54 in.
Deceleration to Stop	-	5 sec.

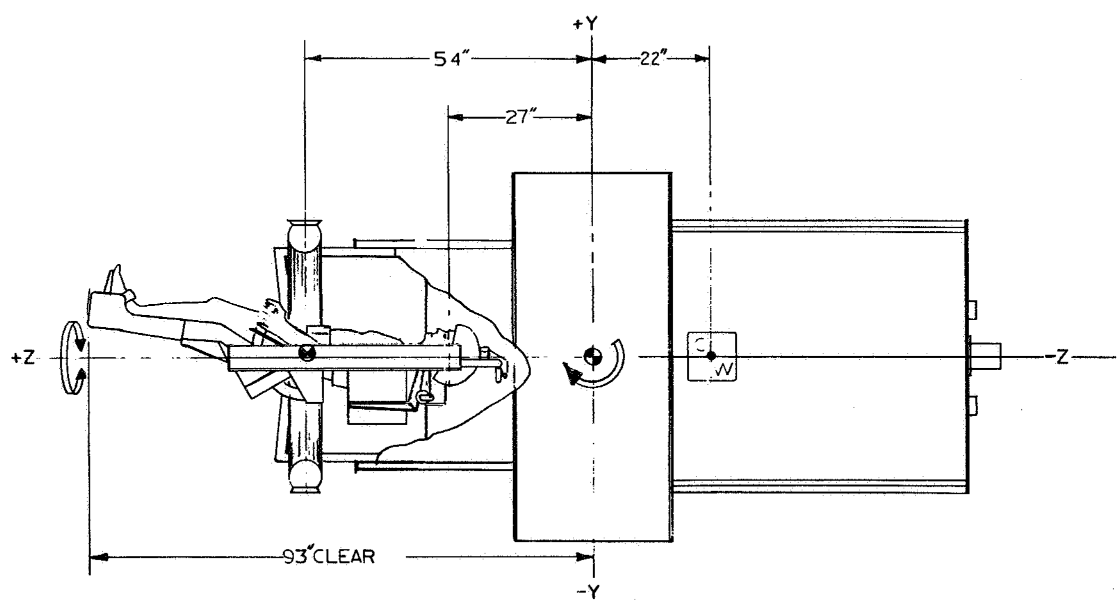

Figure 4. T-010C, Angular Acceleration Threshold

3.1.4 T-010D - Tolerance to Tilt Simulation

Primary Rotation	- 29.6 rpm
Rotation Acceleration (max.)	- .141 Rad/sec^2
Pivot Drive Velocity	- 1.5^o/sec.
Pivot Acceleration (max.)	- .1^o/sec^2
Radius Arm Setting	- 40 inches
Roll Setting	- 90^o
Couch Setting	- 0 inches
Subject C.G. (before tilt)	- 40 inches
Subject C.G. (after tilt)	- 59 inches
Decelerate to Stop	- 5 sec.

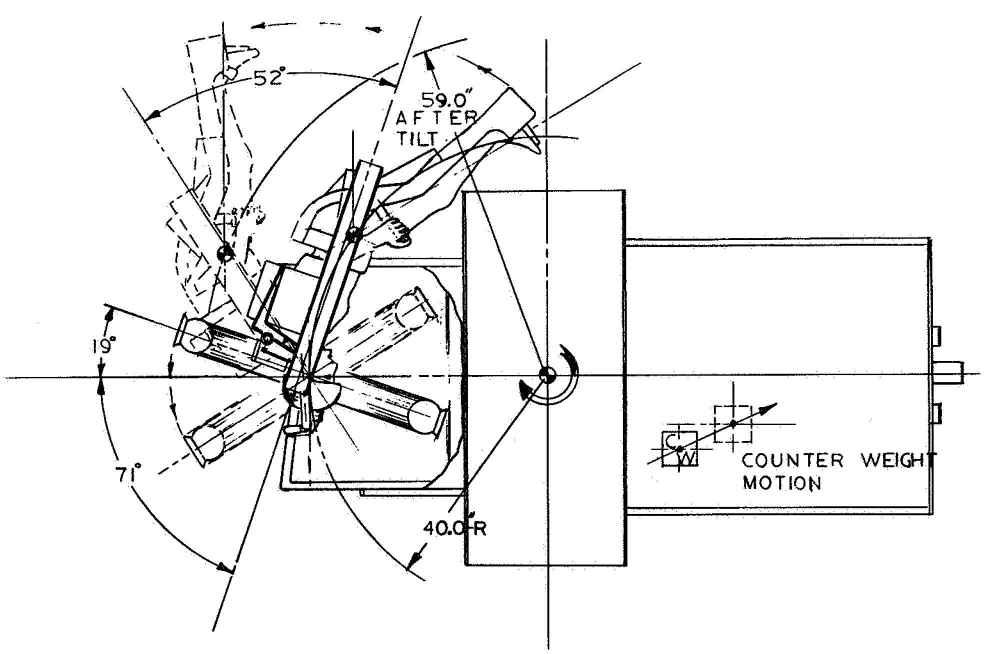

Figure 5. T-010D, Tolerance to Tilt Simulation

3.1.5 T-010E - Semicircular Canal Stimulation and Coupled Angular Accelerations

Primary Rotation	- 4 rpm - 10 rpm	
Acceleration (max.)	- .171 Rad/Sec	
Radius Arm Setting	- 27 in. - 45 in.	
Pivot Setting	- 0	
Couch Settings	- 0.0 in.) - 27 in.)	(Legs half up)
Roll Setting	- 0^o 45^o 90^o	
Subject C. G.	- 27 in. - 72 in.	
Decelerate to Stop	- 5 sec.	

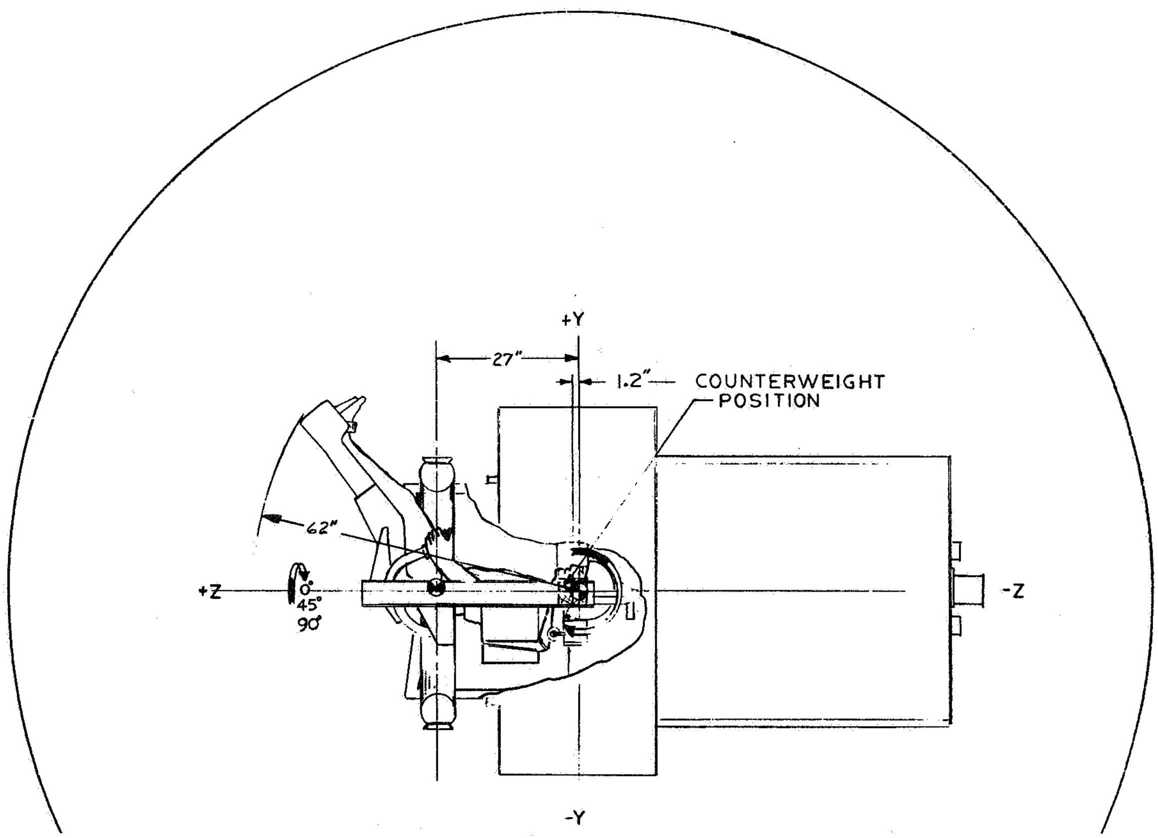

Figure 6. T-010E, Coupled Angular Velocities (Part 1)

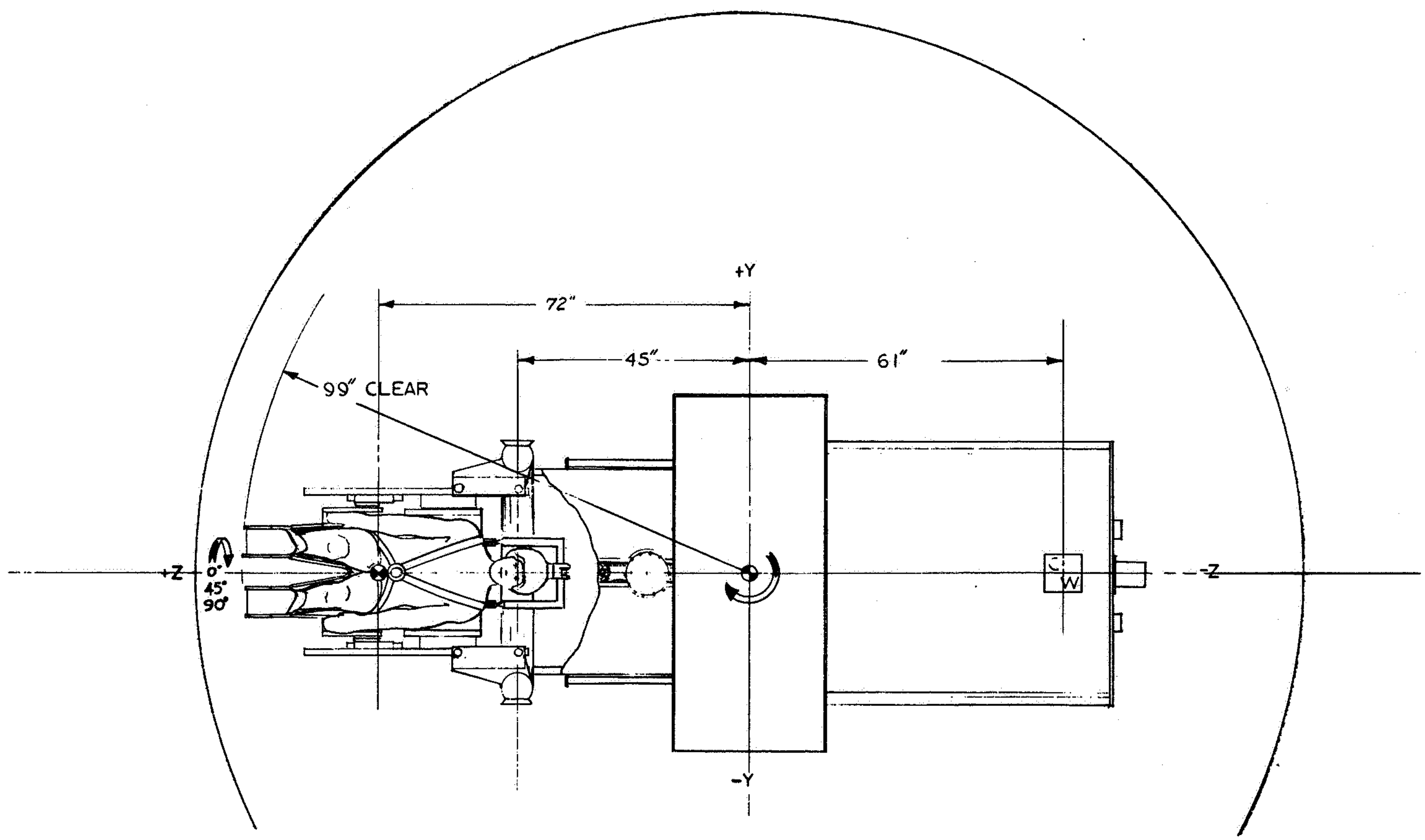

Figure 7. T-010E,Coupled Angular Velocities (Part 2)

3.1.6 T-010F - Otolith Sensitivity to Linear Acceleration

Primary Rotation	- 14 rpm
	- 20 rpm
	- 28 rpm
Accelerations (max.)	- .171 Rad/Sec^2
Radius Arm Setting	- 45 in.
Pivot Positions	- 0^o 15^o 30^o 45^o
Roll Settings	- 0^o, 90^o
Couch Settings	- 0 in. (Legs up)
Subject C. G.	- 72 in. - 0^o Setting
	- 71 in. - 15^o Setting
	- 68.4 in. - 30^o Setting
	- 64.1 in. - 45^o Setting
Decelerate to Stop	- 5 sec.

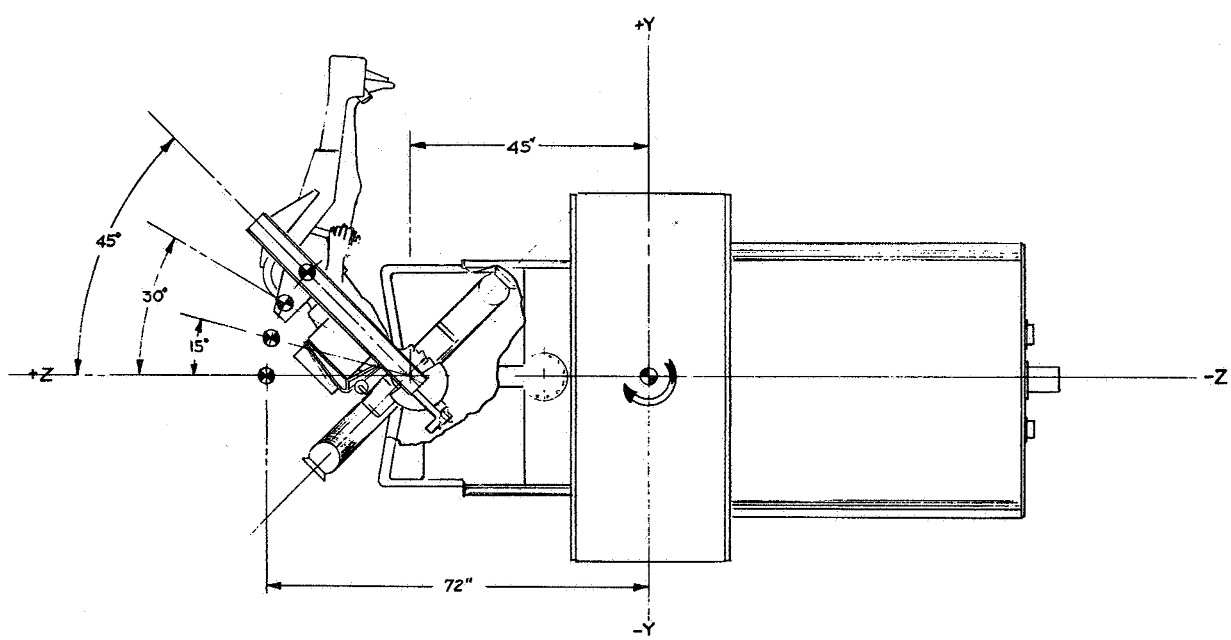

Figure 8. T-010F, Otolith "G" Sensitivity (Part 1)

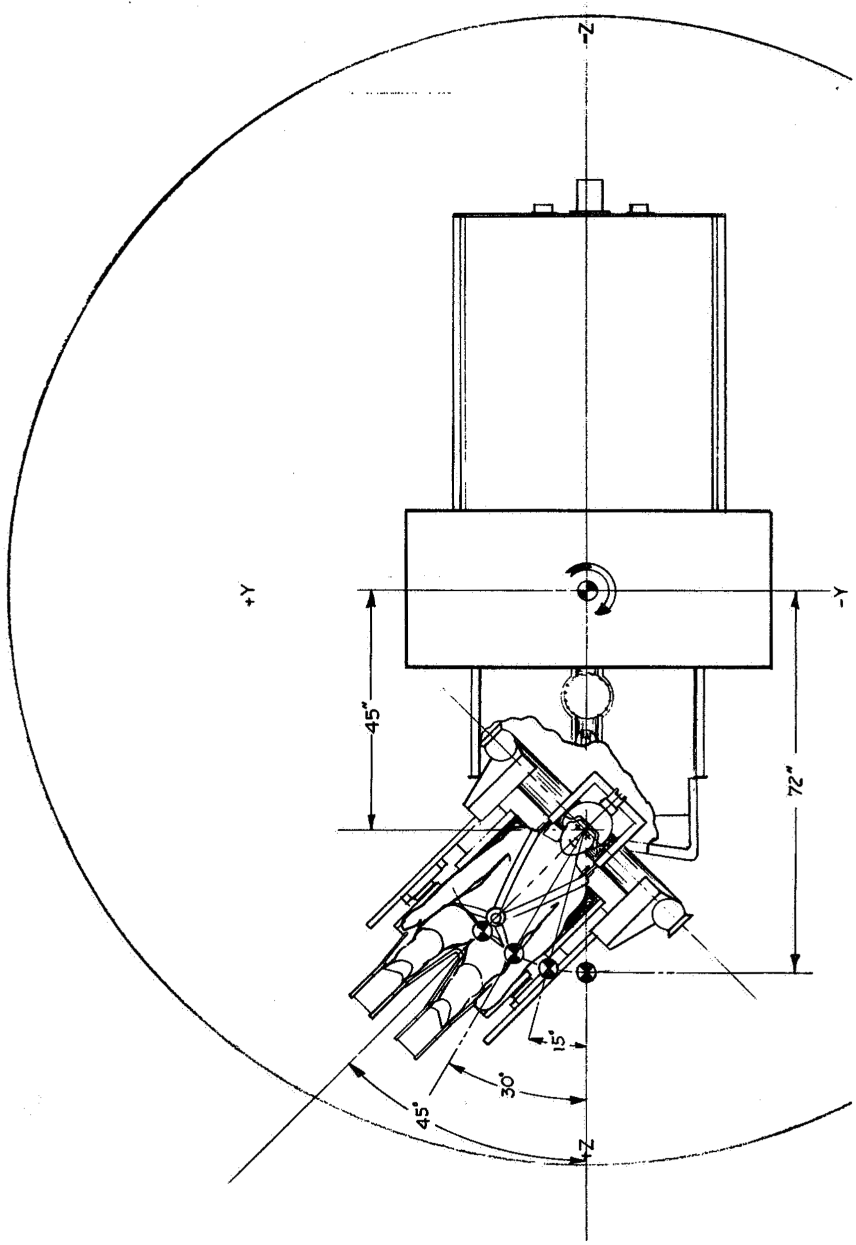

Figure 9. T-010F, Otolith "G" Sensitivity (Part 2)

3.1.7 T-010G - Re-Entry Simulation

Primary Rotation (max.)	-	65 rpm
Acceleration (max.)	-	.171 Rad/Sec^2
Radius Arm Setting	-	76 in.
Pivot Setting	-	78^o
Roll Setting	-	90^o
Couch Setting	-	27 in. (Legs down)
Subject C. G.	-	76 in.
Decelerate to Stop	-	40 sec.

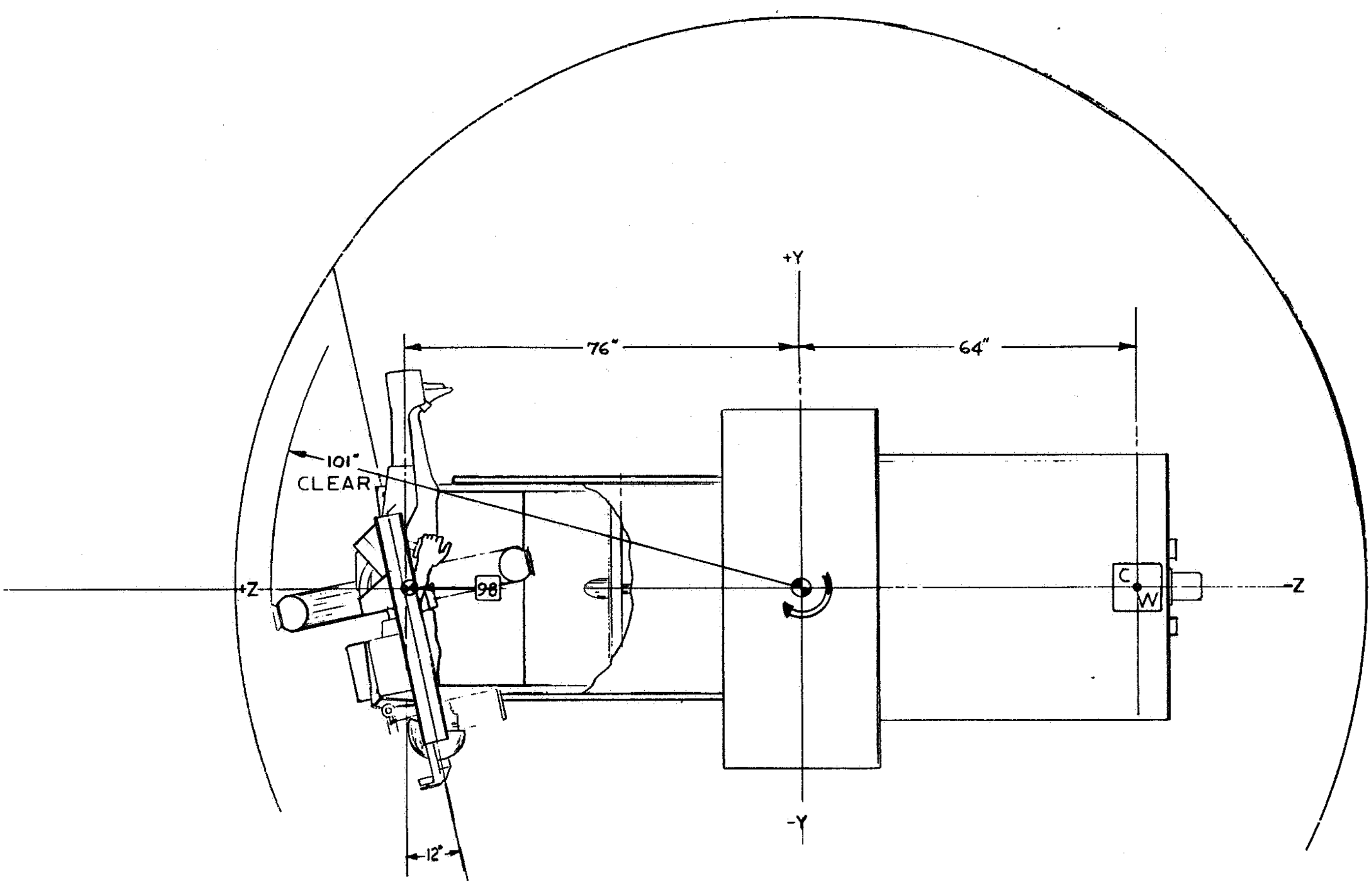

Figure 10. T-010G, Re-Entry Simulation

4.0 SUPPORT FRAME AND PERTURBATION SYSTEM

The centrifuge assembly shall be installed alternately in two attitudes as shown in SRC-SD-110. A single support structure, with suitable adapter sections, shall be designed to include the special features defined herein.

4.1 STRUCTURE

The support structure shall be a square, rigid, platform capable of reacting the maximum static and dynamic loads, from the center-mounted centrifuge, at the four corners.

4.1.2 The structural design shall also enable peripheral attachment of three individual equipment packages weighing as much as 300 lbs.

4.1.3 The center hub assembly shall be readily accessible to permit easy adaptation of the alternate mounting configurations. Bolt on adapter sections shall be designed to permit:

1. in-plane mounting with sensor assembly installed
2. in-plane mounting without the sensor assembly
3. normal-to-plane mounting without the sensor assembly.

4.1.4 A solid floor system shall be provided across the top of the support structure, capable of reacting a concentrated load of 500 lbs/ft^2 at any point.

4.2 FLOTATION SYSTEM

The support frame with the centrifuge mounted thereon shall rest on a system of air bearings operating on four spherically contoured bearing pads.

4.2.1 Bearing support pads shall be mounted rigidly to concrete footings sized to insure maximum stability.

4.2.2 The bearing system shall be capable of floating the entire support frame and centrifuge assembly to simulate rotation of the centrifuge about a spherical radius of 364 in.

4.3 PERTURBATION SYSTEM

4.3.1 A system of hydraulic servo actuators, mounted between the support frame assembly and the concrete footings, shall be capable of simulating the anticipated space station coning motions during centrifuge operations.

4.3.2 With the centrifuge operating, and the support system floating, the hydraulic system shall be able to follow a programmed sinusoidal input up to 3.5 cycles/sec. with a double amplitude not to exceed 1.0 in.

4.4 TORQUE MEASURING SYSTEM

A system shall be provided to accurately measure the acceleration torque and the frictional torque imparted to the support frame. This system will be used to establish design criteria for and to evaluate performance of a counter momentum system.

5.0 SUPPORT SYSTEMS

The following support systems shall be provided as a part of the ground based centrifuge system.

1. Hydraulic Pumping Unit.
2. Air Compressor Unit.
3. Battery Charging Unit.
4. Data Recording System.

6.0 FACILITY REQUIREMENTS

No new facility construction shall be required. The centrifuge system shall, however, be housed in a facility which meets these requirements.

6.1 STRUCTURAL REQUIREMENTS

Min. Floor Size	-	25' x 25'
Unobstructed Ceiling	-	14'
Min. Access Door Size	-	6' x 8'
Floor & Air Bearing Footings	-	Concrete
Equipment Room	-	Acoustically damped partitions

6.2 ENVIRONMENT

6.2.1 The centrifuge enclosure shall be maintained on a routine basis using good standard cleaning practices.

6.2.2 Temperature and humidity control shall be provided.

6.2.3 A secondary, 18 foot dia., enclosure shall be provided to simulate space capsule geometry

6.3 SERVICES

Commercial power and water shall be provided.

SRC-SD-203

DESIGN CRITERIA
For the
ELECTRICAL INSTRUMENTATION AND CONTROL
For the

SPACE RESEARCH CENTRIFUGE
ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER
Contract NAS 1-7309

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1.0 SCOPE

This document establishes the functional, performance and design criteria for the instrumentation and control of a Space Research Centrifuge.

1.1 DEFINITION

All of the components necessary to power, control, instrument and monitor the performance of the Space Research Centrifuge are covered by this document. Biomed instrumentation and accessory equipment peculiar to the different experiments are excluded from this definition.

Included are the following functions:

- Primary Drive Control
- Translation Arm Drive Control
- Pivot Drive Control
- Roll Drive Control
- Counterweight Drive Control
- Couch Abort
- Roll, Pivot, Translation and Counterweight Position Measurement
- Mass Measurement
- Head Turn Measurement
- Telemetry and R. F.
- Manual Control Station
- Operator Control Console
- Closed Circuit TV
- Chamber Lighting
- Voice Communications
- Experiment Equipment Interface

1.1.1 The following documents form a part of this document:

SRC-SD-202 Command, Control and Instrumentation Subsystem

SRC-SD-407 Drive Hub and Sensor System Ground Based Centrifuge

SRC-SD-604 Test Requirements-Space Research Centrifuge

1.1.2 Reference Documents

SRC-MS-112 Experimental Program Development for T-010.

SRC-SD-112 Support Structure, Sensor Hub Interface and Perturbation. Mechanism-Ground Based Space Research Centrifuge.

SRC-SD-110 General Arrangement-Ground Based Space Research Centrifuge.

SRC-SD-403 Main Rotational Frame and Arm/CWT Drive Frame-Structural Assembly

SRC-SD-411 Counterbalance Subsystem-Space Research Centrifuge.

1.2 PURPOSE

The instrumentation and control of the Space Research Centrifuge shall be designed to satisfy all functional and performance criteria, established herein, throughout the normal and emergency modes of operation of the centrifuge.

2.0 INSTRUMENTATION AND CONTROL FUNCTIONS

The components identified in Section 1.1, must accomplish the following primary functions:

1. Condition, distribute and control electrical power for centrifuge operation.
2. Sense, transmit, and read out operating parameters of the centrifuge.
3. Provide logic to control and constrain centrifuge and test subject within safe limits of operation.
4. Provide electrical interface for experiment accessory equipments.
5. Provide audio communications between test subject and test conductor.
6. Provide closed circuit TV coverage of test subject.

2.1 ELECTRICAL POWER

The source of electrical power for the centrifuge is storage batteries. The batteries for the primary drive, the control console and the facility lighting shall be mounted on the facility support structure. The batteries for the rest of the electrical equipment shall be mounted on the rotational frame. The batteries will be recharged between experiments from the ground facility 28 V DC. system.

The power shall be controlled by solid state devices or mechanical switching devices suitable for operation in an explosive atmosphere. Slip rings shall not be used at the rotating joints. Expandable flat strip conductors will be used for signal and power transmission across the variable radius arm and roll and pivot point axes. Expandable flat conductors shall be provided for signal and power transmission between the radius arm assembly and the main rotational frame.

No provision shall be made for transmitting power across the primary rotary joint during rotation since separate battery supplies are provided on the rotating and non-rotating segments.

2.2 SENSING

Sensors shall be provided to measure the critical parameters necessary for the operation and control of the centrifuge. In addition, sensors shall be provided for mass measurement and head turn measurement of the test subject. Signal conditioning, to convert the measurements to a 0-5 volt signal at less than 5000 ohms impedance, shall be installed in close proximity to the sensor installations. Measurements data shall be multiplexed and converted to PCM FM and transmitted via the rotary capacitor to the operator's console where it will be received, decoded and conditioned for display. The data displayed fall into three main categories:

1. Biomed
2. Experiment
3. Centrifuge

The displayed biomed data is obtained from the biomedical belt, sensors attached to the subject, and the TV camera. These data shall be arranged and displayed at the operator's console in a manner to afford the operator optimum visibility of the critical biomed data.

Experiment data shall also be displayed on the biomonitor panel together with the operator's experiment equipment controls. Rater/Logit, the perceptual motor tester and the camera are representative experiment equipment.

The centrifuge operating data shall be displayed on a panel along with the associated controls. Data shall be presented in the simplest go/no-go format that is feasible.

2.3 LOGIC AND CONTROLS

Operation of the centrifuge shall be controlled from the manual control console or the operator's console. The function of the manual console is to provide, at a location near the couch, a means of positioning the centrifuge and couch during the experiment preparations. The manual position controls shall be limited to those required to extend, pivot and roll the couch. Primary drive control and counterweight position controls shall not be provided at the manual console.

The operator's console shall provide means for positioning the centrifuge and counterweights in all degrees of freedom. Additionally, the control logic shall permit the operator to preprogram the operating parameters required during the experiment mode. The control logic shall also include provisions for abort and for limiting the operation of the centrifuge to prevent excursions, forces or speeds that are unsafe for either the subject or the centrifuge.

Interlocks shall be included in the logic to prevent improper sequencing of operations or operating the centrifuge in a configuration or mode that does not conform to the equipment or experiment requirements.

The logic for the primary drive automatic mode shall prevent its operation until the mechanical locks are engaged for the roll, pitch and translation mechanisms.

The logic for the roll drive, automatic mode, shall prevent its operation until the mechanical locks are engaged for the pitch, translation and primary rotation mechanisms.

2.4 EXPERIMENTS EQUIPMENT, ELECTRICAL INTERFACE

Accessory equipment mounted on the couch shall be required in conjunction with the biomed instrumentation during the conduct of the experiments. Since different accessory equipment must be installed, depending upon the type of experiment, suitable electrical receptacles shall be installed on the couch to permit plugging in several equipments at one time. Twenty eight volts dc, shall be made available from the centrifuge battery supply. Regulated power, and ac power shall be provided as part of the accessory equipment. Pins shall also be included in the receptacles for the remote control and readout of the accessory equipment functions at the operator's console.

2.5 AUDIO COMMUNICATIONS

Two-way audio communications shall be provided between the couch and the operator's console. A microphone and a loudspeaker will be installed at the operator's console. At the couch, headphones shall be provided in the head restraint and a throat microphone provided for the test subject. The audio signals shall be transmitted between the two positions via F.M. to eliminate wire circuits between them. A sensing system shall be incorporated in the audio link to detect a failure in the audio communications and signal the operator.

2.6 CLOSED CIRCUIT TV

A closed circuit TV system shall be required for observing the subject during test. The system shall consist of a camera and controls located on the couch and a TV monitor located on the biomonitor panel at the operator's console.

3.0 PERFORMANCE REQUIREMENTS

The electrical instrumentation and control of the engineering development prototype of an orbital space research centrifuge shall be capable of operating in or after having been exposed to the environments of ground test, earth launch, boost to orbit, and orbital operation. Additionally, the components shall satisfy the performance requirements outlined in the following paragraphs.

3.1 PRIMARY DRIVE, ELECTRICAL

The primary drive, electrical, provides the electrical power and control for the operation of the Space Research Centrifuge primary drive mechanism.

A variable speed 4HP, 3 phase motor direct-coupled to the primary drive gear box is required to drive the Space Research Centrifuge at the desired rates. The motor speed shall be continuously variable within the range of 35-3500 rpm. A tachometer shall be provided as an integral part of the motor for speed regulation and for read-out purposes.

An electric brake shall be provided to decelerate the centrifuge within safe limits. Braking logic shall be such that the brake will be applied in the absence of electrical power. A deceleration time constant shall be incorporated to cause the brake to stop the centrifuge from a speed of 65 rpm in 15 sec. minimum and 30 sec. maximum.

The primary drive speed and rate of accelerating and decelerating shall be set by the operator at the operator control console. This programmed input shall be routed through the primary drive logic unit to the ramp generator. The ramp generator shall provide a time varying signal to the primary drive comparator for comparison with the tachometer output. The resultant signal shall be fed to the three phase inverter to change the amplitude and frequency of the output to the motor. The brake shall be dc operated.

The dc power for the brake and the three phase inverter shall be furnished from the battery supply mounted on the centrifuge support structure.

3.2 TRANSLATION ARM DRIVE, ELECTRICAL

The translation arm drive, electrical, provides the electrical power and control for the translational movement of the centrifuge arm.

A two speed 1/3 HP, 115 v, 400 Hz, three phase intermittent duty induction motor direct coupled to the translation arm gear box shall be required to position the centrifuge arm at the desired radius. The motor shall be operated at either 10, 800 rpm for large position changes or 2, 460 rpm for small changes. A Forward/Reverse control and a Fast and Slow Translation control shall be furnished only at the manual control console for operation by the test monitor.

An electric brake shall be provided on the motor to hold the translation arm at the desired radius. Logic shall be such that the brake shall be applied in the absence of electric power.

A three phase 115 v, 400 Hz inverter shall be required to furnish the power for the 1/3 HP motor. The brake shall be dc operated. The battery supply mounted on the centrifuge arm shall furnish the power input to the brake and the inverter.

Indicator lights, one for each of the five arm positions, shall be mounted on the operator's console. The appropriate light shall be on when the arm is locked in one of the positions.

3.3 PIVOT DRIVE, ELECTRICAL

The pivot drive, electrical, provides the electric power and control for the pivoting of the roll frame.

A two speed, 1/3 HP, 115 v. 400 Hz, three phase intermittent duty induction motor direct coupled to the pivot drive gear box shall be required to position the roll frame at a rate of 2^{o}/sec. or 10^{o}/sec. Motor speeds shall be 2, 460 rpm or 10, 800 rpm. An electric brake shall be furnished with the motor to hold the roll frame at the desired pivot angle. Logic shall be such that the brake will be applied in the absence of electric power.

Controls for the pivot drive shall be provided at both the manual control console and the operator's console. The control at the manual console shall be confined to slow speed drive in the "+" or "-" directions. No readout shall be provided since the operator can directly observe the roll frame angle of rotation.

Controls to operate the pivot drive in either direction at slow or fast speed shall be located at the operator's console. A digital position indicator and light indicators for 0^{o} and $+ 90^{o}$ lock status shall also be provided. Control logic shall prevent operation of the pivot drive in either locked position.

A three phase 115 volt, 400 Hz inverter shall be required to power the 1/3 HP motor. DC power for the brake and the inverter shall be obtained from the battery supply mounted on the centrifuge arm.

3.4 ROLL DRIVE, ELECTRICAL

The roll drive, electrical, provides the electrical power and control for the couch roll movement.

A variable speed 28 volt dc brushless motor directly coupled to the roll drive gear box shall be used to position the roll frame and couch at the desired angle and to provide programmed varying angular accelerations to the subject. An electric brake shall be provided on the motor to hold the roll frame at the desired angle. Logic shall be such that the brake will be applied in the absence of electric power.

Roll drive shall be controlled from either the operator's console or the manual control console. At the manual console the operator shall be able to rotate the roll frame in either direction at one speed. No readouts shall be provided at the manual console since the operator can observe directly the roll frame position. Readouts of roll acceleration, velocity and 0^{o} and 90^{o} lock status shall be provided at the operator's console. Controls shall be provided to rotate the roll frame in either direction at the fast or the slow speed. An automatic control mode shall also be selectable at the operator's console. In the automatic mode the roll acceleration and velocity amplitudes and durations shall be variable in accordance with commands sent from the main control logic unit to the roll ramp generator. The test subject's real time response to the experiment shall determine the succeeding roll commands.

The battery supply mounted on the centrifuge arm shall be used to power the roll drive motor and brake.

3.5 COUNTERWEIGHT DRIVE, ELECTRICAL

The counterweight drive, electrical, provides the electrical power and control for the positioning of the centrifuge arm counterweights.

Three 1/3 HP, 115 volt, 400 Hz three phase 11,000 rpm induction motors shall be direct coupled to the counterweight drive gear boxes. One motor shall provide the translation motion for the upper and lower counterweights through one mechanical drive assembly. The transverse motion of the upper and lower counterweights shall be accomplished by providing a motor at each counterweight and slaving one motor to the other such that the upper and lower counterweights move together. An electric brake shall be furnished with each motor to hold the counterweights at the desired position. Logic shall be such that the brake shall be applied in the absence of electric power.

Controls shall be provided at the operator's console to position the counterweights either manually or automatically. A three phase 400 Hz, 115 volt inverter shall be required to provide the electric power for the motors. The power for the brake and the inverter shall be obtained from the 28 volt dc battery system mounted on the centrifuge arm.

Readout on the operator's console shall include the magnitude and polarity of the translation and transverse forces and the position of the counterweights in the translation and transverse directions. Digital shaft encoders mounted on the lead screws shall provide the position data. Force transducers mounted on the centrifuge arm shall provide the information for the readout and the counterbalance positioning servo controls.

3.6 COUCH ABORT, ELECTRICAL

The couch abort, electrical, provides the logic and the means for the test subject to terminate the centrifuge experiments at any time. An abort switch shall be mounted on the couch to permit the test subject to stop the centrifuge during any mode of operation. The control logic shall be such that the abort switch overrides all centrifuge drive commands.

3.7 ROLL, PIVOT, TRANSLATION AND COUNTERWEIGHT POSITION SENSORS, ELECTRICAL

The roll, pivot, translation and counterweight position sensors, electrical, provide the signals for the readout and control of these parameters.

The roll position shall be measured from 0^{o} to 360^{o} to an accuracy of $\pm 3^{o}$. The pivot position shall be measured over the range of $+100^{o}$ to -100^{o} to an accuracy of $\pm 2^{o}$. The translation position range of measurement shall be 49 inches with an accuracy of $\pm$ 0.10 in. The counterweight longitudinal position measurement range shall be 64 in. at an accuracy of 0.10 in. The counterweight transverse position measurement range shall be $\pm$ 15 inches at an accuracy of $\pm$ 0.10 in.

3.8 MASS MEASUREMENT, ELECTRICAL

The mass measurement, electrical, provides the means for instrumenting the mass of the astronaut. Four force transducers shall be mounted on the couch support frame and shall sense the magnitude of the force of the couch and the astronaut. When subjected to a one-g centrifugal force, reacted through the couch frame, the resultant force shall be the sum of the four sensors. The output of the four sensors shall be summed, conditioned and displayed on the biomonitor panel. Full scale measurement shall be no greater than 1/8 in. displacement when subjected to a 500 lb. force.

3.9 HEAD TURN MEASUREMENT, ELECTRICAL

The head turn measurement, electrical, provides the means to measure and readout the test subject's head position during the conduct of the experiments. The head restraint device when unlocked shall allow head motion about the Y and Z axes. Potentiometers attached to the pivots at the two axes shall provide voltages proportional to the angular displacements. These data shall be displayed on the biomonitor panel. Full scale measurement shall be $\pm 50^{o}$.

3.10 TELEMETRY AND RF

The telemetry and RF equipment required for the Space Research Centrifuge shall multiplex, encode, transmit, receive and reproduce the biomedical data, the experiment equipment data, the closed circuit TV and the centrifuge operating parameters. Data handling shall be in either analog or digital format, depending upon the accuracy required or the type of display. The TV and voice communications will be analog. The biomedical data, the experiment equipment data, and the centrifuge operating parameters will be digitized. Data not required on a continuous basis shall be commutated to permit time sharing of TLM channels. TLM channel components shall be modularized to permit adding or deleting components in accordance with changes in the instrumentation measurements.

Communications, biomedical data, and couch operating parameters used in the angular acceleration test shall be segregated in one TLM channel to facilitate transmission through either a rotary capacitor or omni antennas.

Rotary capacitors located at the primary drive will provide the primary RF link between the centrifuge arm and the operator's console. In the angular acceleration test setup the roll frame electrical harness is disconnected at the pivot gear box to permit 360° roll travel. The RF link in this mode of operation will be through an omni directional antenna, facing the chamber wall, mounted on the couch roll axis, and a facing omnidirectional antenna mounted on the temporary mockup chamber wall.

3.11 MANUAL CONTROL CONSOLE, ELECTRICAL

The manual control console, electrical, provides the means for positioning the centrifuge and the couch in preparation for the experiments. Controls shall be provided for the translation arm drive, pivot drive, and the roll drive. No position readouts shall be provided since the operator can directly observe the centrifuge and couch. Panel illumination shall be provided to permit operation of the controls at low ambient light levels. Power for the console shall be provided by the 28 volt batteries mounted on the centrifuge arm.

3.12 OPERATOR CONTROL CONSOLE, ELECTRICAL

The operator control console, electrical, provides the means for positioning and controlling the centrifuge and the couch and ancillary equipment during the conduct of the experiment. It also permits operation of the primary drive for pre-and-post-experiment operations. Controls shall be provided for manually operating the primary drive, translation drive, pivot drive, roll drive and counter-weight drive.

Illumination level control of the chamber and experiment equipment control shall also be accomplished from the operator's console. Panel illumination shall be provided to permit operation of the controls at low ambient light levels.

3.13 CLOSED CIRCUIT TV, ELECTRICAL

The closed circuit TV, electrical, provides the means for televising the test subject face during the experiments and displaying a black and white picture on the biomonitor panel. A vidicon camera shall be mounted on the couch for this purpose. Scanning pattern shall be 525 lines per frame, 30 frames per sec. The picture shall be transmitted on channel 3. Transmission shall be through a rotary capacitor at the primary drive. Camera circuitry shall operate on 28 volts dc from batteries mounted on centrifuge arm.

Camera optics shall cover a field 15" high x 20" wide at 40" from lens. Depth of field shall be 36" to 50". Lens focus and iris shall be manually adjustable. Illumination at subject's face shall be 20 foot candles minimum.

A 8 inch monitor shall be provided on the biomonitor panel to display the vidicon picture.

Controls shall be accessible to the operator for adjustment of picture brilliance, contrast, focus and synchronization. The monitor shall operate from 28 volts dc.

3.14 CHAMBER LIGHTING, ELECTRICAL

Chamber lighting shall be provided to illuminate the centrifuge access areas, service areas, steps and walks at an average intensity of 20 foot candles.

Lighting shall be provided at the experiment set-up area to illuminate the area around the couch at a level of 70 foot candles during the experiment preparation activity. Control shall be provided to reduce the level to 30 foot candles. Lamps shall be capable of operating in an explosive atmosphere.

Chamber lighting switches shall be provided at the operator's console. 28 volts dc from the battery pack in the chamber shall be the source of power for the lights.

3.15 VOICE COMMUNICATIONS, ELECTRICAL

The voice communications, electrical, provides the means for oral communications between the test subject on the couch and the operator at the operator's control console. A throat microphone and headset shall be provided at the couch for the test subject. The test subject shall also be provided a headset volume control. A loudspeaker and microphone shall be installed at the operator's control console. A bandwidth of three KHz on the FM link shall be allocated for the audio signal. A tone generator shall be provided at the operator's console to generate a signal for transmission on the FM link. The received tone at the couch shall be retransmitted for reception at the operator's console. Absence of a tone shall be detected and an indicator light shall signal the operator that the audio link is inoperative.

3.16 EXPERIMENT EQUIPMENT INTERFACE, ELECTRICAL

An electrical interface shall be provided at the couch for mating the biomed belt and the experiment equipment mounted on the couch with the centrifuge controls, readout and power.

An umbilical connector and cable shall be provided for connecting the biomed belt to the centrifuge TLM equipment.

Two female receptacles shall be installed on the couch to provide 28 volt dc power, 0-28 volt dc power and switch closures for equipment logic.

A fourth connector shall be provided for transmission of data from the experiment equipment for telemetering, experiment command logic or readout on the operator's control console.

The four connectors shall be of different sizes or clocking to preclude interconnecting the wrong cables.

3.17 PERTURBATION CONTROL, ELECTRICAL

The perturbation control, electrical, furnishes the means of controlling the actuators used to move the air bearing support structure of the Space Research Centrifuge prototype to simulate the anticipated dynamic environment. The control system shall be capable of controlling the motion of the air bearing support structure over the range of 0 to $\pm$ 6 inches in the X-Y plane at frequencies from 0 to 1 cpm max. with the capability of a superimposed motion of 0 to $\pm$ 0.25 inches (zero to peak amplitude) from 0.10 to 1.0 Hz, and 0 to $\pm$ 0.05 inches (zero to peak amplitude) from 1.0 - 3.5 Hz. Limiters shall be included in the circuity to prevent excursions in excess of those stated above. The excitation of the actuators shall be either in phase, to cause motion in the X direction or the Y direction, or a quadrature phase relationship to cause a circular motion. Accelerometers will be mounted on the centrifuge arm at various points to monitor the structural response of the centrifuge to the dynamic perturbations. Test facility recorders shall be used to record these data.

Force transducers will also be installed to measure the X-Y forces reacted from the primary drive bearing through the air bearing support structure to the air bearing pads. The primary drive transmission and bearing losses can be determined by subtracting these forces from the electric drive motor torque.

Controls and readout will be located at the systems performance console.

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

The design of the electrical instrumentation and control for the

Space Research Centrifuge prototype shall conform in general to Section 6.0 (GDC Drawing SRC-SD-407). Functional capabilities and interface provisions shall be as shown to assure functional and physical compatibility with interfacing assemblies.

4.2 STANDARDS

Materials, finishes, fabrication and assembly practices shall be in accordance with conventional aerospace quality standards.

4.3 WEIGHT

Flight weight design is not a requirement, due to the accompanying expense, but emphasis should be placed on selecting components that are representative of flight hardware concepts and can be weight optimized later.

4.4 SPECIFIC GROUND RULES

Specific ground rules in the design are as follows:

Control circuit logic design will use "fail safe" logic.

Combustible materials shall not be used.

Electrical switching shall be explosion-proof.

Design will incorporate maximum interchangeability of electrical and electronic parts to facilitate maintenance, repair, and spares provisioning.

An electrical grounding system will be provided connecting the facility ground to the centrifuge, the electric motors, and the electronic chassis.

Adequate means shall be employed to maintain parts within their maximum permissible operating temperature under all operating conditions.

Controls and adjustments shall be accessible and of such size and construction as to permit ease of operation under all service conditions.

Circuit test facilities shall be provided on the chassis of the equipment. Sufficient test points shall be provided to enable a quick check of replaceable minor subassemblies and complex components.

Use of special test equipment, test fixtures or tools will be kept at a minimum.

Caution notices shall be provided where voltages are in excess of 500 volts.

4.5 RELIABILITY

The electrical instrumentation and controls shall, in the finally accepted configuration, meet the minimum reliability requirements applicable to the Man-Rated Space Research Centrifuge Program.

5.0 ACCEPTANCE

Initial acceptance of the electrical instrumentation and controls shall be based on the satisfactory demonstration of performance as a unit. The final acceptance demonstration will be accomplished in conjunction with all other elements of the Space Research Centrifuge.

SUB-SYSTEM SPECIFICATION

For the

DRIVE HUB AND SENSOR SYSTEM

For the

SPACE RESEARCH CENTRIFUGE

ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract NAS-1-7309

Prepared by

CONVAIR DIVISION OF GENERAL DYNAMICS
San Diego, California

By: for D. L. Browning

Approved: J. Stumm

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1.0 SCOPE

This specification establishes the functional, performance, and design requirements of the Drive Hub and Sensor Sub-System for a Space Research Centrifuge Engineering Development Prototype.

1.1 DEFINITION

The Drive Hub and Sensor Sub-System is an electro-mechanical assembly connecting the rotating centrifuge to the facility support structure. It shall consist of the following system elements:

1. Drive Hub/Bearing Assembly
2. Sensor/Cross Bridge Assembly
3. Rotary Capacitor

1.1.1 The following documents form a part of this specification.

SRC-SD-407 Drive Hub and Sensor System Ground Based Centrifuge

SRC-SD-604 Test Requirements-Space Research Centrifuge

1.1.2 Reference Documents

SRC-MS-112 Experimental Program Development for T-010.

SRC-SD-112 Support Structure, Sensor Hub Interface and Perturbation Mechanism-Ground Based Centrifuge.

SRC-SD-110 General Arrangement-Ground Based Space Research Centrifuge.

SRC-SD-111 System Specification-Space Research Centrifuge Engineering Development Prototype

SRC-SD-202 Instrumentation

SRC-SD-403 Main Rotational Frame and Arm/CWT Drive Frame-Structural Assembly.

SRC-SD-409 Primary Drive Sub-System.

SRC-SD-411 Counterbalance Sub-System-Space Research Centrifuge.

1.2 PURPOSE

The Drive Hub and Sensor Sub-System shall be designed to satisfy all functional and performance requirements, established herein, throughout the full regime of operational modes including emergency stop and maximum force inbalance conditions.

2.0 SYSTEM FUNCTIONS

The sub-system must accomplish the following primary functions:

1. Provide structural continuity between the centrifuge main rotating frame and the facility support structure.
2. Provide the rotational interface between the centrifuge and the facility.
3. Provide structural and mechanical interfaces with the primary drive system (motor, gear box, and brake assembly).
4. Measure forces due to "static" imbalance of the rotating centrifuge during all modes of operation.
5. Transfer electrical data signals across the rotational interface.

2.1 STRUCTURAL CONTINUITY

The structural load path through the hub/sensor assembly is provided by a sensor cross bridge structure, the sensor assemblies and their supports, and a drive hub assembly composed of two concentric barrels and two bearings. Continuity at the centrifuge interface is furnished by joining the 30 inch O.D. centrifuge attach ring (a component of the cross bridge assembly) to a square planer structure formed by the end channels of the centrifuge main rotational frame and lateral beams spanning between them. Internal continuity across the bearings is achieved by incorporating sufficient bearing preload to prevent both axial and lateral motion of the rotating portion of the hub with respect to the fixed portion during all load conditions. Four support longerons, integral with the outer portion of the drive hub assembly, provide a vertical load interface through lap joints with the facility structure. Torsional loads are carried through a bolt circle connecting the outer barrel of the hub assembly to a circular plate in the support structure. Lateral loads are shared by the two paths. An internal bolted joint between the cross bridge structure and the hub assembly is provided to permit individual buildup, test, and installation of these assemblies.

2.2 ROTATIONAL INTERFACE

The centrifuge rotational interface is provided by the drive hub and bearing assemblies. Two identical bearings, together capable of reacting all thrust and radial loads, are positioned and held within the drive hub assembly by retaining rings integral with the inner and outer hub barrel assemblies. Each bearing consists of inner and outer races, balls, and a teflon ball spacer which also serves to lubricate the balls. Pre-loading is achieved by shimming one of the bearing retaining rings on the outer hub barrel assembly. Circular seals utilizing teflon rubbing surfaces prevent bearing contamination.

2.3 DRIVE SYSTEM INTERFACE

Structural mounting for the primary drive assembly (motor, gear box, and brake) is provided by a waffle-stiffened circular plate attached to the open end of the outer barrel assembly. Provision for final slignment of the primary drive assembly shall be included. The interface with the drive motor pinion is accomplished by a ring gear integral with one bearing retainer of the inner torque cylinder.

2.4 FORCE MEASUREMENT

A planar array of six identical force sensor assemblies, geometrically aligned with the coordinate axes of the rotating centrifuge, are employed to determine the magnitude of forces resulting from "static" imbalance of the rotating centrifuge. (Static imbalance is defined as an offset of the centrifuge center of mass from the axis of spin, which produces a radial force normal to the spin axis through the mass center.) The sensors provide a primary structural tie, directly carrying all normal operational loads between the centrifuge attach ring and the remainder of the cross bridge structure, which otherwise floats freely on the ring via teflon pads at four jaw fittings. Adjustable structural stops are provided on the ring to allow for any emergency overload conditions.

Each sensor assembly is comprised of a force transducer, differential screw micrometer adjustor, and a tension tie rod to the ring. Force measurement signals are transmitted by hard wire from each transducer to the centrifuge balance system logic units.

2.5 ELECTRICAL SIGNAL TRANSFER

Transfer of electrical signals across the rotational interface is accomplished by a rotary capacitor assembly aligned along the spin axis within the hub inner torque cylinder. A parallel beam assembly, with an integral center box, supports the outer body of the capacitor. The capacitor shaft is in turn attached to the drive motor support plate by a self aligning insulator block and a bracket which spans the open center bay of the plate. Coaxial cables connect the capacitor with the electrical systems it serves.

3.0 PERFORMANCE REQUIREMENTS

The drive hub and sensor assembly is a subsystem of the engineering development prototype of an orbital space research centrifuge. Therefore, its performance criteria must include the requirement of maintaining complete functional integrity of all subsystem elements when exposed to the various environments of ground test, earth launch, boost to orbit, and orbital operation. The following paragraphs reflect this full spectrum of performance requirements.

3.1 STRUCTURE

The structure must be capable of sustaining, with adequate margins of safety, all loads applied at the centrifuge and drive motor interfaces during both normal and emergency operating conditions. These loads include, but are not limited to: maximum inertia loadings in all coordinate axes; maximum imbalance forces (occurring with the centrifuge arm fully extended, no counterweight compensation, and a normal acceleration of 9.0 g at the couch); spin-up deceleration torques; and any vibrational loadings.

In addition to adequate strength, the total drive hub and sensor sub-system structural assembly must possess stiffness compatible with that of the entire centrifuge assembly to assure adequate separation of the total system natural frequencies from all operational frequencies.

3.2 ROTATIONAL SYSTEM

The rotational system must possess a minimum useful life of 5,000 hours of operation. Throughout this lifetime it must remain noiseless and retain line-to-line fit of all bearings within the races by applying and maintaining suitable preload. The life of the unit shall be independent of the order, duration, or repetitive frequency of approved tests.

3.3 DRIVE SYSTEM INTERFACE

Structural criteria are specified in Section 3.1. The ring gear shall possess a minimum useful life of 5,000 hours of operation, during which it must remain noiseless in operation and free of adverse wear. It will form a dry interface with the primary drive motor pinion. As with the bearings, the life of the gear shall be independent of the order, duration, or repetitive frequency of approved tests. Gear parameters shall be:

1. Pitch diameter - 16.00 in.
2. Diametral pitch-5
3. Number of teeth-80
4. Pressure angle-14.5^{o}.
5. Material-hard anodized aluminum alloy.
6. Rated for 4 HP.

3.4 FORCE SENSING SYSTEM

All sensor assemblies shall be identical. The force sensors (transducers) shall possess a minimum useful range of 0-200 lbs, with sufficient sensitivity and functional tolerance to provide a usable output at 0.5 lbs. The micrometer adjustment shall permit accurate preloading of the assembly to 100 $\pm$ 0.5 lbs. to maintain tension in the assembly over the full range of normal operational loads. The overload stops shall be positioned to preclude loading during normal system operation but yet to protect the transducers from damage in any overload situation.

It shall be mandatory that the force sensing system be capable of detecting static imbalances of 10 lbs or greater in any coordinate direction. A further objective of the system shall be to detect at 5 lbs. or above, but it is recognized that this capability is highly dependent on the minimizing of frictional forces at the jaw fittings.

3.5 ELECTRICAL SIGNAL TRANSFER

A rotary capacitor shall be utilized to transfer bio-monitoring and systems status signals across the rotational interface to and from the facility controls and displays. (Note: Slip rings are not permitted for this application.) The capacitor shall pass closed circuit TV signals on Channel 3. All other signals will be either time or frequency multiplexed and transmitted on Channels 12 through 19.

Capacitance for the higher channels shall be approximately 300 $\mu\mu$fd. The portion of the capacitor carrying TV signals shall be shielded and insulated from the remainder of the unit to minimize cross-talk and RF interference.

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

The design of the drive hub and sensor system shall conform, in general, to Section 6.0 (GDC Drawing SRC-SD-407). Dimensional envelopes shall be as shown and hard callout dimensions shall be held. Interface provisions shall be as shown to assure compatibility with interfacing assemblies.

4.2 STANDARDS

Materials, finishes, and fabrication and assembly practices shall be in accordance with conventional aerospace quality standards.

4.3 WEIGHT

Flight weight design is not mandatory, due to accompanying high costs, but emphasis should be placed on providing components which are representative of flight hardware concepts and which can later be weight optimized.

4.4 SPECIFIC GROUND RULES

Specific ground rules in the design are as follows:

1. Slip rings will not be permitted for use in electrical data transfer (Reference Section 3.5)
2. Cables will not be permitted for use as tension ties in the sensor assemblies.

3. Materials of low combustibility shall not be used.
4. A removable shroud shall be provided around the sensor assemblies.

4.5 RELIABILITY

The drive hub and sensor sub-system shall, in the finally accepted configuration, meet the minimum reliability requirements applicable to the Man-Rated Space Research Centrifuge Program.

5.0 ACCEPTANCE

Initial acceptance of the sub-system shall be based on the satisfactory demonstration of performance as a unit. The final acceptance demonstration, however, will be accomplished with the sub-system integrated with all other elements of the Space Research Centrifuge.

SRC-SD-410

SUB-SYSTEM SPECIFICATION

for the

PRIMARY DRIVE SUB-SYSTEM

for the

SPACE RESEARCH CENTRIFUGE ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract No. NAS-1-7309

Prepared by

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1.0 SCOPE

This specification defines the sub-system requirements for the design and fabrication of the primary drive sub-system for a space research centrifuge.

1.1 DEFINITION

The primary drive sub-system shall include the following system elements.

1. Drive Motor
2. Transmission System
3. Drive Gear and Pinion
4. Braking System
5. Tachometer

1.1.1 Documents

The following documents form a part of this specification.

Primary Drive Sub-system, SRC-SD-409

Test Requirements - Space Research Centrifuge, SRC-SD-604

1.1.2 Reference Documents

"Space Research Centrifuge"
General Arrangement Dwg., SRC-SD-110
System Specification, SRC-SD-111

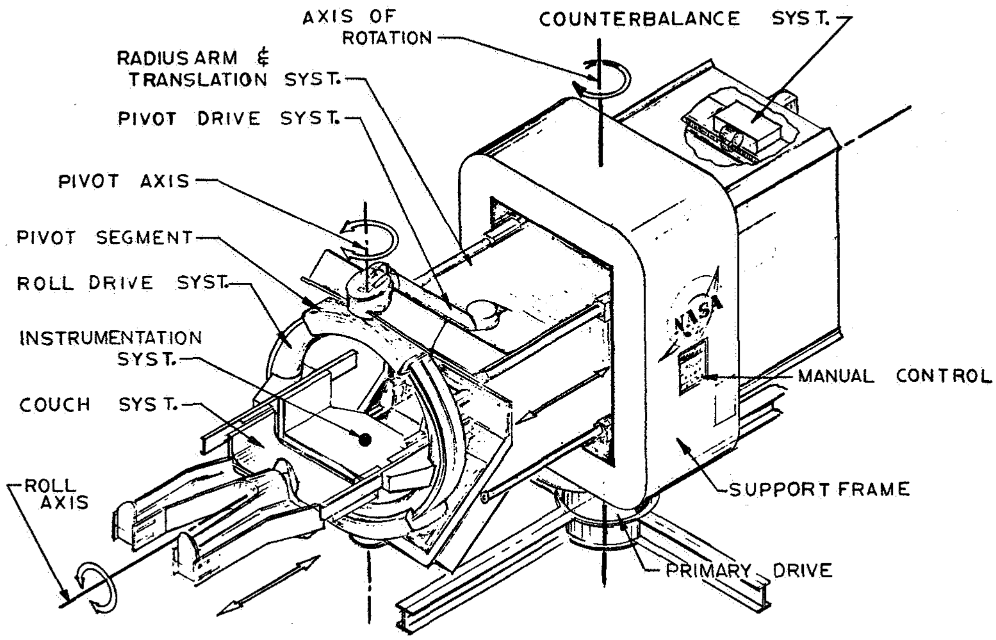
Instrumentation Sub-system, SRC-SD-202

Drive Hub and Sensor Sub-system, SRC-SD-407

Experimental Program Development for T-010, SRC-MS-112

1.2 PURPOSE

Presently defined experiments (SRC-MS-112) for the space research centrifuge program establish a range of precisely controlled, rotational velocities from 0-rpm to 47 rpm as a minimum requirement. The primary drive system will be designed to provide these capabilities plus the ability to create a centrifugal force field equivalent to 9 g units at the maximum radius of the astronaut couch. (Ref. Fig. 1)



Ground Based Centrifuge (Reference Figure 1, SRC-SD-111)

2.0 FUNCTIONAL REQUIREMENTS

The primary drive sub-system, when integrated with the drive control system (SRC-SD-202), shall provide these capabilities.

2.1 MANUAL OPERATION

When in the manual mode, the drive unit shall be capable of responding, at the predetermined rate of acceleration, to any selected centrifuge velocity between .65 rpm and 65 rpm.

2.2 AUTOMATIC OPERATION

In the automatic drive mode, the unit shall have a capability of following a preprogrammed acceleration profile to the varying velocity levels necessary to simulate the "g" environment of an Apollo re-entry.

2.3 STOPPING CHARACTERISTICS

The drive system shall be designed to respond to stop commands in a controlled fashion. From any velocity level the unit shall be capable of a smooth, constant rate deceleration to a full stop within 30 seconds. The deceleration ramp shall be .23 rad/sec^2.

2.3.1 Drive Brake

A positive acting, failsafe, mechanical holding brake shall be incorporated into the drive system design. The brake shall be electrically released as a sequential function of a drive command.

3.0 PERFORMANCE REQUIREMENTS

When integrated with the space research centrifuge, the primary drive sub-system shall meet the following performance requirements.

3.1 Drive system operation shall be smooth, quiet, and free of vibration.

3.2 The drive unit shall include a tachometer for continuous readout of drive speeds.

3.3 Deviation from linearity of the output shaft speed versus the control signal shall not exceed 0.1% over the entire speed range.

3.4 Motor overload protection with automatic reset shall be provided.

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

The basic envelope and interface requirements for the primary drive sub-system shall be as shown on Dwg. SRC-SD-112 and shall consist of:

1. Drive Motor
2. Transmission
3. Drive Gear and Pinion
4. Braking System
5. Tachometer

4.1.1 Drive Motor

1. 4-pole - 120 cycle - 3-phase - induction type.
2. Hp rating: 4 hp at 3480 rpm.
3. Variable speed control from 34.8 rpm to 3480 rpm.
4. Reversible.
5. Thermal overload protection with automatic reset.
6. Control signal 0-10 volts.
7. Sealed unit - no sparking and no contamination generation external to the unit shall occur when the unit is placed in a chamber with a 1-psi environment.

4.1.2 Transmission

1. Speed reduction - 13:1
2. Sealed unit - no contamination generation external to the unit shall occur when the unit is placed in a chamber with a 1-psi environment.
3. With the output shaft locked and the brake disengaged the unit shall withstand the full stall torque of the drive motor without deformation.
4. The gear box assembly, with motor, shall mount onto the hub and sensor assembly.
5. The unit shall be designed for a useful life of 5000 hours of operation with no increase in noise level or other indication of wear.
6. A holding brake shall be provided in the gear box.
7. A tachometer of the magnetic pulse generator type shall be integrated into the drive transmission.

4.1.3 Drive Gear and Pinion

The driven ring gear is integrated into the drive hub bearing retainer ring (Ref. SRC-SD-407), as part of the inner torque cylinder assembly. Provision is made in the drive system mounting bracket for gear spacing and alignment. The drive pinion gear shall be designed to mesh with a ring gear of the following type.

1. Pitch diameter - 16 in.
2. Diametral pitch - 5.
3. Number of teeth - 80.
4. Pressure angle - 14.5°.
5. Material aluminum alloy - hard anodized.
6. Rated for 4 hp.

4.1.3.1 The pinion gear shall be precision quality and shall exhibit quiet, smooth, vibration free performance, without backlash, when meshed with the driven ring gear. A pinion gear of the following type shall be developed.

1. Pitch diameter - 5 in.
2. Diametral pitch - 5.
3. Number of teeth - 20.
4. Pressure angle - 14.5 .
5. Material - laminated Teflon and epoxy or non-flamable fiberglass- with aluminum side plates.
6. Rated for 4 hp.

4.2 CONTROL SYSTEM

The space research centrifuge control sub-system requirements are defined in the instrumentation sub-system document, SRC-SD-202. The primary drive sub-system shall be compatible with the requirements defined therein.

4.3 WEIGHT

All elements of the primary drive sub-system design shall be weight optimized to react only the loads, plus a suitable safety margin, imposed by operation in a zero "g" environment. The additional loads imposed during ground operations shall be compensated for by removable bracing and/or stiffening designed specifically for the application.

4.4 RELIABILITY

The drive sub-system shall, in the finally accepted configuration, meet the minimum reliability requirements applicable to the Man-Rated Space Research Centrifuge Program.

5.0 ACCEPTANCE

Initial acceptance of the drive unit shall be based on the satisfactory demonstration of performance as a unit. The final acceptance demonstration, however, will be accomplished with the sub-system integrated with the control system and other elements of the Space Research Centrifuge.

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SRC-SD-412

SUB-SYSTEM SPECIFICATION

For the

COUNTERBALANCE SUB-SYSTEM

For the

SPACE RESEARCH CENTRIFUGE

ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract NAS-1-7309

Prepared by

CONVAIR DIVISION OF GENERAL DYNAMICS
San Diego, California

By R. Saunders   Approved J. Stumm

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1.0 SCOPE

This specification defines the sub-system level of requirements for a Counterbalance System to be incorporated in a Space Research Centrifuge engineering development prototype.

1.1 DEFINITION

The counterbalance sub-system, as described herein, shall consist of a system of weights, electrically driven, which can both translate along the centrifuge arm and move transversely to the arm. Principle elements of the sub-system are: (Reference- Figure 1).

1. Counterweight Battery Unit (2 required).
2. Transverse Drive Assembly (2 required).
3. Counterweight Frame Assembly (2 required).
4. Counterweight Translation Drive and Distribution Assembly.
5. Expandable Conductor System.

1.1.1 Documents

The following documents form a part of this specification.

Counterbalance Sub-system SRC-SD-411.
Test Requirements-Space Research Centrifuge SRC-SD-604.

1.1.2 Reference Documents

Space Research Centrifuge General Arrangement Dwg. SRC-SD-110.

System Specification - SRC-SD-111.

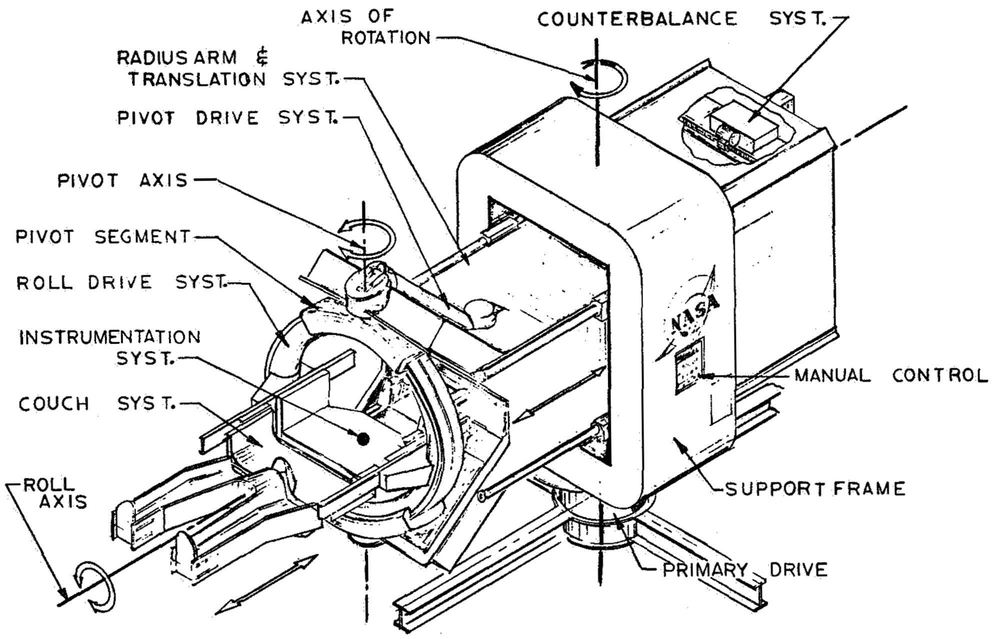
Instrumentation Sub-system - SRC-SD-202.

Drive Hub and Sensor Sub-System - SRC-SD-407.

Experimental Program Development for T-010, SRC-MS-112

1.2 PURPOSE

A variable radius arm, which is required to provide the necessary degrees of flexibility to meet the Space Research Centrifuge test requirements, creates a wide range of variation in the mass distribution of the centrifuge. Additionally, some of the experimentation requires that the couch and test subject be pivoted about the pivot axis (Ref. Fig. 1) while the centrifuge is rotating. The intent of this specification is, therefore, to develop an initial design for a system of automatically counteracting the in-plane unbalanced forces which can occur as a result of static unbalance in the rotating system.



Ground Based Centrifuge (Reference Figure 1, SRC-SD-111)

2.0 FUNCTIONAL REQUIREMENTS

The counterbalance sub-system shall provide the following functional capabilities.

2.1 MANUAL OPERATION

When integrated with the centrifuge control sub-system, the counterbalance assembly shall enable the accurate positioning of the counterweights from both the manual control station, at the centrifuge, and from the remotely located test monitor's console.

2.2 AUTOMATIC OPERATION

While the centrifuge is rotating, the counterbalance subsystem shall automatically respond to the unbalance signals, generated at the sensor hub (Ref. SRC-SD-407) to move the counterweight assemblies and thereby counteract the unbalance condition.

2.4 ABORT OPERATION

The counterbalance sub-system shall be able to maintain the centrifuge static balance within the acceptable limits during all acceleration or deceleration excursions, including an abort stop.

3.0 PERFORMANCE REQUIREMENTS

With the counterbalance sub-system installed on the Space Research Centrifuge and integrated with the force sensor and instrumentation sub-systems, the following performance requirements shall be met.

3.1 GENERAL OPERATION

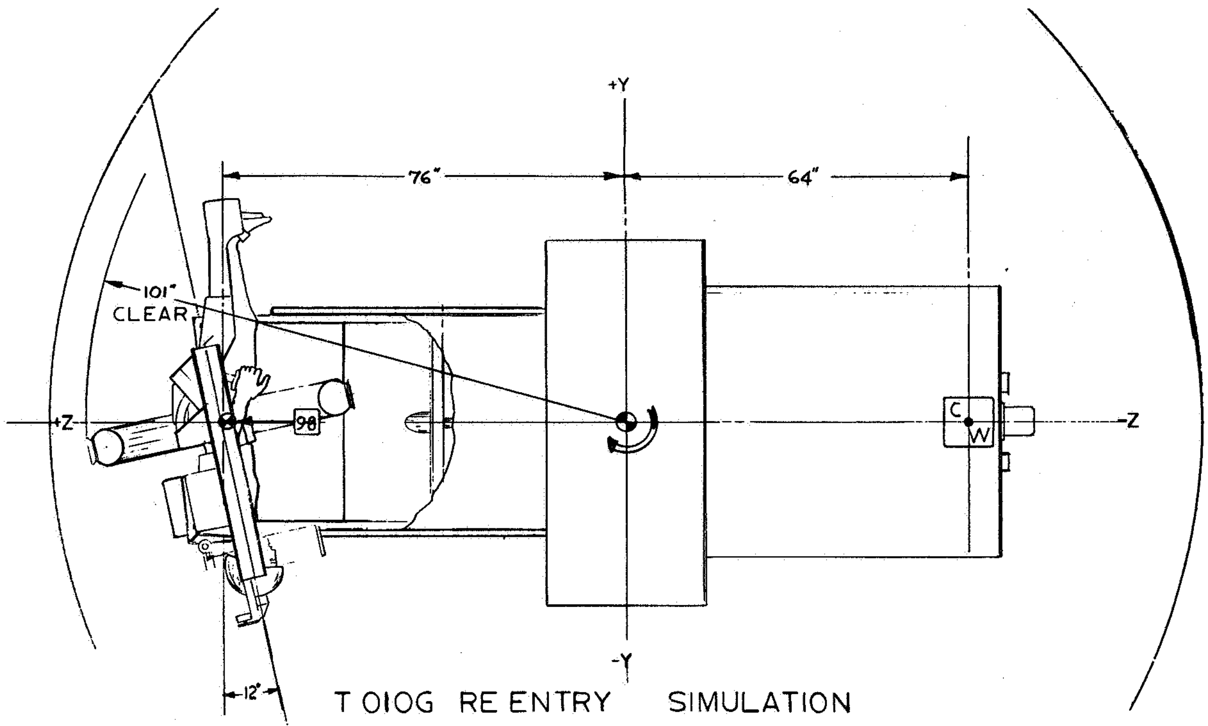
In all modes of operation, the counterbalance system shall perform quietly and provide for accurate, vibration-free positioning of the counterweight assemblies. Smoothness of operation, without hunting, shall be a primary consideration.

3.2 POSITIONING REQUIREMENTS

Positive positioning of the two counterweight masses shall be within $\pm$ .125 inch of any commanded position within the defined envelope. Position variations between the counterweights shall not exceed $\pm$ .06 inches.

3.3 RESPONSE

Changes in the couch and test subject orientation during the rotational experiment can cause a change in static balance at a rate of .5 inch/sec. The sub-system shall be able to compensate for this rate of change without exceeding the allowable unbalance force limit of 10 lbs.



(Reference Figure 1, SRC-SD-111)

3.4 STRUCTURAL

The structural elements of the counterbalance sub-system shall provide sufficient stiffness and structural integrity to react the maximum inertia loadings of the counterweights, in all axes, while in a 9.0 g environment and operating. All counterweight loads shall be reacted through the main rotational frame. (Ref. SRC-SD-110).

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

Drawing SRC-SD-411 defines the interfaces and installation geometry for the counterbalance sub-system. The major sub-system elements are:

1. Counterweight Battery Units (2 required).
2. Transverse Drive Assembly (2 required).
3. Counterweight Frame Assembly (2 required).
4. Translation Drive and Distribution Assembly (2 required).
5. Expandable Conductor Assemblies (2 required).

4.1.1 Counterweight Battery Unit

Utilization of the storage batteries as a part of the counterweight system shall be accomplished to the maximum extent possible commensurate with battery packaging capabilities. As a baseline, the following requirements shall be met.

1. Each battery unit shall be a detachable, plug-in type unit.
2. Output = 28V DC, 210 Watt-hours full charge.
3. Unit shall be rechargeable from a remote connection.
4. Unit shall be replaceable without the use of tools.
5. Electrical connections to the battery unit shall be designed such that forces acting on the unit, during centifuge rotation, will tend to make rather than break the connections.
6. Minimum battery life shall be 2 years with a minimum of 150 charge-discharge cycles to 50% of full charge level.

4.1.2 Transverse Drive Assembly

The transverse drive assemblies shall be designed to structurally support the battery units and provide for controlled positioning of the units transversally to the centrifuge primary axis.

4.1.2.1 Load Factors

1. The centrifugal loads, and the resultant components, imposed by the assembled battery and drive unit shall be reacted into the counterweight frame tracks through a system of teflon covered rollers attached to the transverse drive frame.
2. Transverse loads shall be carried through a rigidly fixed ball screw into the counterweight frame assembly. The ball screws shall be designed for an initial tension

pre-load to prevent excessive compression loading on the screws, and shall be capable of reacting inertial loads resulting from 15 sec. emergency stops of the centrifuge.

4.1.2.2 Drive Assembly Components

1. Drive Motor and Brake Assembly.

   a. 115V - 400 C.P.S., 3-phase-AC type.

   b. Rated @ 1/4 HP.

   c. Explosion Proof

   d. Reversible.

   e. Life 5000 Hr. continuous duty.

   f. Minimum brake holding torque - 30 oz.-in.

   g. Braking Response = .1 sec. full speed to stop.

2. Drive Transmission

   a. Speed Reduction = 30:1.

   b. Sealed Units - No contamination generation shall occur, external to the unit, when placed in a chamber at 1 psia atmospheric pressure.

   c. With the output shaft locked and the brake released, the unit shall withstand full stall torque of the motor without deformation.

   d. The motor, transmission and ball screw assembly shall be installed as a unit onto the transverse drive frame.

   e. The unit shall be provided with a position feedback device of sufficient accuracy to support the control stability requirements.

   f. Design Life - 5000 Hrs. operation without indication of excessive wear.

   g. Smooth operation with zero backlash.

4.1.3 Counterweight Frame Assembly

The counterweight frame shall be designed to structurally support the total mass of the moving portion of the counterweight system, and shall provide for precise, controlled positioning of the counterweights along the centrifuge primary axis.

4.1.3.1 Load Factors

1. Centrifugal loads (but not their components) shall be reacted into the main rotational frame through a fixed ball nut, on the frame assembly, and a rotating ball screw which is mounted on the main centrifuge frame. The ball screw system and its support structure shall be designed for an initial tension pre-load of a value which is sufficiently high to prevent compression loading on the ball screws. For 9-g experiments the counterweights will be positioned to transmit the centrifugal load directly into the main frame.

2. The transverse inertial loads, and their components, plus the weight loads (-1g earth environment) shall be reacted through a system of ball bushings, or rollers, into the continuous beam and guide rail assemblied which are integrated into the main frame.

4.1.4 Translation Drive and Distribution Assembly

Mounted on the aft end of the main rotational frame will be a system comprising a drive motor and transmission assembly, a distribution gear box, and two 90^{o} miter gear boxes with interconnecting shafts. These units provide a mechanical link between the upper and lower counterweight systems to insure synchronous positioning. Position feedback shall be provided in the transmission or distribution assemblies.

4.1.4.1 Drive Motor and Transmission Assembly

1. Drive Motor and Brake Assembly.

   a. 115V-400 C.P.S., 3-phase-AC type.

   b. Rated @ 1/3 H.P.

   c. Explosion proof.

d. Reversible.

e. Life - 500 Hr. continuous duty.

f. Brake response = .1-sec. full speed to stop.

g. Brake holding torque 40 oz.-in.

2. Transmission Assembly.

a. Speed reduction 31:1 (approximate).

b. Sealed unit - no contamination generation shall occur, external to the unit, when operating in a chamber at 1-psia atmospheric pressure.

c. Output - speed = 360 R.P.M.
torque = 50 in.-lbs.-min.

d. With the output shaft locked and the brake released, the unit shall withstand full motor stall torque without deformation.

e. Design Life - 5000 Hr. of operation without indication of excessive wear.

f. Smooth, quiet operation with zero backlash.

3. Distribution and 90° Miter Gear Boxes.

a. The distribution gear box shall have an interfacing sealed flange mating to the drive transmission, and shall provide two splined output shafts 180° apart.

b. The upper and lower 90° miter gear boxes shall be identical and shall provide the interface connection between the drive shafts and the driven ball screws.

c. Speed ratio 1:1 - all units.

d. Units shall be of the precision type, providing smooth, quiet power distribution. Backlash between the upper ball screw and the lower ball screw shall not exceed 20 arc-seconds.

e. Design life = 5000 Hr. of operation without indication of excessive wear.

f. Units shall not generate external contamination when exposed to a 1-psia atmospheric pressure.

g. The inner connecting shafting shall have at least one universal joint on each shaft. Spline fittings and universal joints shall be of precision quality and shall provide positive innerconnection of the distribution assemblies.

h. Torque tube windup shall be considered as part of the backlash limitation.

4.1.5 Expandable Conductors

Electrical power to and from the counterweight drives and battery unit shall be transmitted through expandable, self retracting, flat wire cables as defined in SRC-SD-203.

4.2 CONTROL SYSTEM

The counterbalance sub-system shall comply with the performance requirements specified herein, and shall be compatible with the Hub and Sensor Sub-System, SRC-SD-407, and the Command and Control Sub-System, SRC-SD-202.

4.3 WEIGHT

All elements of the counterbalance sub-system design shall be weight optimized to react only the loads (plus a safety factor of 1.5) imposed by operation in a zero "g" environment. To the maximum extent possible, the elements of drive system shall be utilized as part of the counterweight mass. Special stiffening and or removable bracing shall be designed to meet load conditions resulting from ground operations.

4.4 RELIABILITY

The counterweight sub-system shall, in the finally accepted configuration, meet the minimum reliability requirements applicable to The Man-Rated Space Research Centrifuge Program.

5.0 ACCEPTANCE

Initial acceptance of the drive unit shall be based on the satisfactory demonstraction of performance as a unit. Final acceptance demonstrations shall be accomplished with the sub-system integrated with the control system and other elements of the Space Research Centrifuge.

SUB-SYSTEM SPECIFICATION

For the

RADIUS ARM TRANSLATION DRIVE SUB-SYSTEM

For the

SPACE RESEARCH CENTRIFUGE

ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract NAS-1-7309

Prepared by

CONVAIR DIVISION OF GENERAL DYNAMICS
San Diego, California

By R. Saunders Approved J. Sturm

R. Saunders J. Sturm

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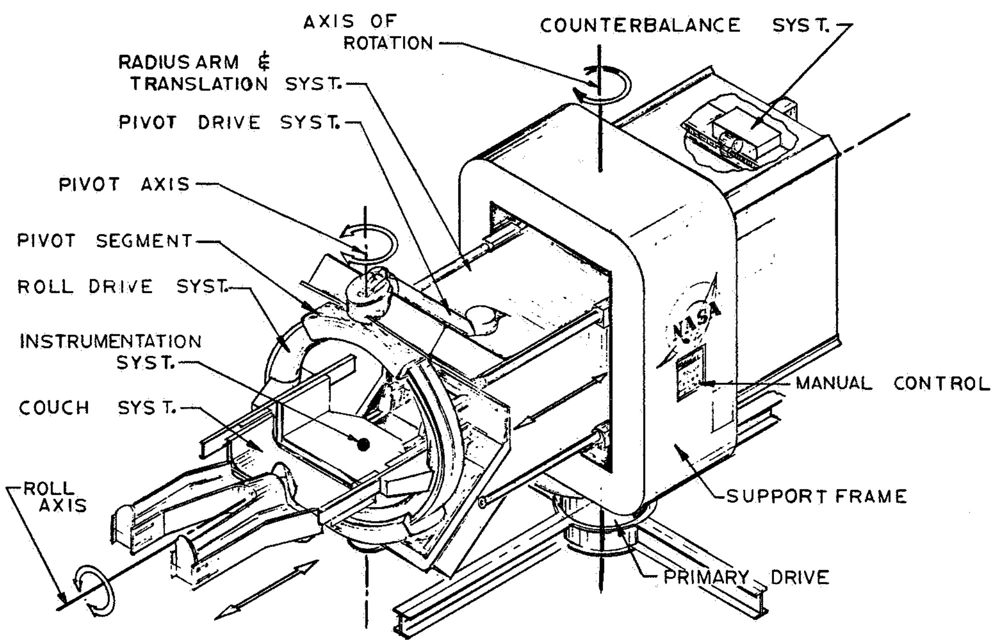
1.0 SCOPE

This specification defines the sub-system level of requirements for a translation drive sub-system to be incorporated into a Space Research Centrifuge Engineering Development Prototype.



Ground Based Centrifuge (Reference Figure 1, SRC-SD-111)

1.1 DEFINITION

The translation drive sub-system, as described herein, shall consist of a drive motor and transmission system driving a ball screw which is mounted on the main rotational frame. A fixed ball nut, which is mounted to the radius arm structure, transmits the ball screw torque into linear translation of the radius arm.

1.1.1 Documents

The following documents form a part of this specification,

Translation Drive Sub-system -SRC-SD-413

Test Requirements, Space Research Centrifuge SRC-SD-604

1.1.2 Reference Documents

Space Research Centrifuge

General Arrangement - SRC-SD-110

System Specification - SRC-SD-111

Command and Control Criteria - SRC-SD-202

Experimental Requirements for the Space Research Centrifuge, SRC-MS-112

1.2 PURPOSE

Experimental requirements (SRC-MS-112) dictate that the Space Research Centrifuge have a wide range of adjustment capability. One of the adjustment requirements involves varying the radius of the test subject and couch center of mass with respect to the primary axis of rotation. The intent of this specification is, therefore, to develop an initial design for an electric drive system which will permit controlled, effortless, translation of the centrifuge radius arm.

2.0 FUNCTIONAL REQUIREMENTS

The translation drive sub-system shall have the following functional capabilities.

2.1 OPERATION

The sub-system shall be designed to operate through a simple on/off, manually operated, control system. A suitable braking system shall be incorporated into the design which will stop the radius arm translation if either power or the command signal is lost.

2.2 POSITIONING

Detailed positioning of the radius arm within the stroke envelope shall be provided.

3.0 PERFORMANCE REQUIREMENTS

With the translation drive integrated with the radius arm support system, the ball screw assembly and the centrifuge control system, the following performance requirements shall be met.

3.1 SUB-SYSTEM OPERATION

Operation of the drive shall be smooth, quiet, and positive acting, and shall enable the accurate positioning of the radius arm by visual reference.

3.2 RESPONSE REQUIREMENTS

When a drive command is terminated, or in case of power failure, the sub-system shall decelerate to a full stop within .2 seconds.

3.2.1 Radius Arm Speeds

Normal Running Speed = 1.0 inch/sec.

Slow Running Speed (creep control) = 0.2 inch/sec.

Acceleration Rate (maximum) = 5 inch/sec^2

3.3 STRUCTURAL

The structural elements of the translational drive shall provide sufficient stiffness and structural integrity to react the maximum translational loads resulting from centrifuge rotation, at 65 RPM, with the manual locks unlocked and the system not operating.

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

The translation drive installation interface is defined on drawing SRC-SD-411. The major sub-system elements are:

1. Ball Screw Assembly
2. 90° Miter Gear Box Assembly
3. Drive Motor and Transmission
4. Manual Locking System

4.1.1 Ball Screw Assembly

Translation of the radius arm is accomplished through a fixed ball nut, mounted on the arm structure, which travels along a rotating ball screw mounted on the main rotational frame. The ball nut shall be designed for zero backlash and low atmospheric contamination.

The ball screw shall be designed for an initial tension preload to prevent excessive compression loading.

4.1.2 90° Miter Gear Box

a. Ratio 1:1

b. Gear box will provide the interface connection between drive transmission and the driven ball screw.

c. Units shall be of the precision type, providing smooth, quiet, vibration free operation with zero backlash.

d. The assembly shall not generate external contamination when operated in a chamber at 1-psia atmospheric pressure.

e. Design life - 5000 Hr. of operation without indication of excessive wear.

4.1.3 Drive Motor and Transmission

4.1.3.1 Motor and Brake Assembly

a. 115V - 400 CPS, 3-phase - AC type.

b. Rated at 1/4 H.P.

c. Explosion proof -

d. Reversible.

e. Life - 5000 Hr. continuous duty.

f. Brake response .2 sec. full speed to stop

g. Brake holding torque 55 oz.-in.

4.1.3.2 Transmission Assembly

a. Speed reduction 46:1 - approximate .

b. Output - speed - 240 rpm - fast
48 rpm - slow
torque - 50 in-lb-min.

c. Assembly shall not generate contamination, external of the unit, when exposed to 1-PSIA atmosphere.

d. With the output shaft locked and the brake released, the unit shall withstand full motor stall torque without deformation.

e. Design life 5000 Hr. of operation without indication of excessive wear.

f. Smooth, quiet operation with zero backlash.

4.1.4 Manual Locking System

A manual locking mechanism shall be designed to rigidly lock the radius arm to the main rotational frame during experimentation which does not require arm translation. The manual locks shall be capable of reacting the combined loads of a stalled drive system, and the inertia loads acting on the radius arm during 65 rpm operation without deformation.

4.2 CONTROL SYSTEM

The translation drive sub-system shall comply with the performance requirements specified herein while being operated through the control system specified per drawing No. SRC-SD-202.

4.3 WEIGHT

All elements of the translation drive sub-system shall be weight optimized to react only the loads (plus a safety factor of 1.5) imposed by operation in a zero " g' environment. The additional loads imposed during ground operations shall be compensated for by removable bracing and/or stiffening designed specifically for the application.

4.4 RELIABILITY

The drive sub-system shall, in the finally accepted configuration, meet the minimum reliability requirements applicable to the Man-Rated Space Research Centrifuge Program.

5.0 ACCEPTANCE

Initial acceptance of the drive sub-system shall be based on the satisfactory demonstration of performance as a unit. The final acceptance demonstration, however, will be accomplished with the sub-system integrated with the control system and other elements of the Space Research Centrigure.

SUB-SYSTEM SPECIFICATION

For the

PIVOT DRIVE SUB-SYSTEM

For the

SPACE RESEARCH CENTRIFUGE

ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract NAS-1-7309

Prepared by

CONVAIR DIVISION OF GENERAL DYNAMICS
San Diego, California

By ______________________ R. Saunders

Approved ______________________ J. Stumm

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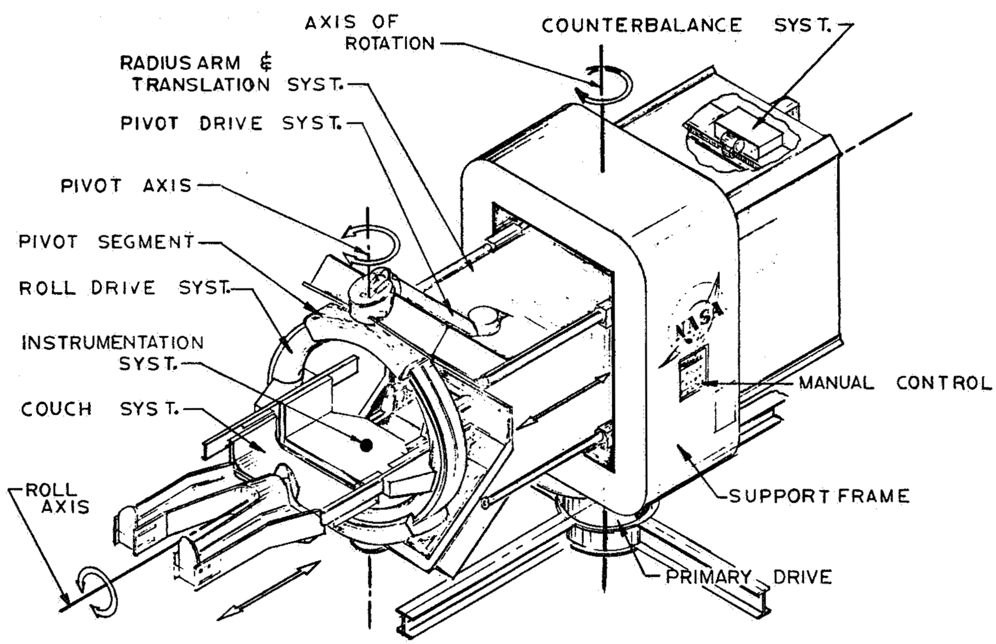
1.0 SCOPE

This specification defines the sub-system level of requirements for a Pivot Drive Sub-System to be incorporated into a Space Research Centrifuge Engineering Development Prototype.



Ground Based Centrifuge, (Reference Figure 1, SRC-SD-111)

1.1 DEFINITION

The pivot drive sub-system shall consist of the following elements.

1. Drive Motor and Transmission
2. Primary Distribution Gear Box
3. Transition Gear Boxes (2-Required)
4. Pivot Gear Box Assembly (2-Required)
5. Torque Shafting

1.1.1 Documents

The following documents form a part of this specification

Pivot Drive Sub-System SRC-SD-415

Test Requirements - Space Research Centrifuge-
SRC-SD-604

1.1.2 Reference Documents

Space Research Centrifuge

General Arrangement Dwg. SRC-SD-110

System Specification SRC-SD-111

Command, Control and Instrumentation

Sub-System SRC-SD-202

Experimental Program

Development for T010 SRC-MS-112

1.2 PURPOSE

Experimental requirements, as defined in reference document SRC-MS-112, establish a need to adjust the test subject position radially, about the pivot axis, while rotating in the centrifuge in the plane of spin. The intent of this specification is to develop an initial design for an electrically driven system to provide test subject rotation about the pivot axis of the centrifuge.

2.0 FUNCTIONAL REQUIREMENTS

The Pivot Drive Sub-system shall have the following capabilities.

2.1 OPERATION

When integrated with the centrifuge control sub-system (SRC-SD-202), the pivot drive shall respond to commands from either the Manual Control Station, on the main rotational frame, or from the remotely located test monitors console.

2.2 MOTION REQUIREMENTS

The sub-system shall enable rotation of the pivot segment, roll frame and subject couch assemblies through $\pm$ 100 degrees from the primary centrifuge in the plane of spin.

3.0 PERFORMANCE REQUIREMENTS

With the drive sub-system integrated into the radius arm and pivot system structure,the following performance level shall be met.

3.1 GENERAL OPERATION

Operation of the system shall be quiet and positive acting and shall provide for smooth, vibration-free rotation of the pivot segment/roll frame and couch assembly about the pivot axis at variably controlled rates between $.1^{\circ}$/sec and 10°/sec.

3.2 POSITION CONTROL

Position accuracy shall be within $\pm$ 1 degree of any commanded position within the 200° pivot range.

3.3 STRUCTURAL

The structural elements of the system shall provide sufficient stiffness and structural integrity to react the combined centrifugal and inertial loads resulting from a one second stop of the centrifuge from rotational speed of 28 R.P.M. with the manual locking system disengaged.

3.3.1 The pivot drive manual locking device, when engaged, shall be able to transmit the maximum torque loads resulting from a one second stop of the centrifuge from a rotational speed of 65 rpm, into the radius arm structure without loading the other drive system elements.

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

Drawing SRC-SD-415 defines the interfaces and installation geometry for the Pivot Drive Sub-System. The major sub-system elements are,

1. Pivot Gear Box Assemblies (2-Required)
2. Transition Gear Box Assemblies (2-Required)
3. Distribution Gear Box Assembly
4. Drive Motor and Transmission

4.1.1 Pivot Gear Box Assemblies

Two pivot gear boxes, installed 180° apart, provide torque and load distribution to support the pivot drive requirements. These units shall be of precision quality and shall exhibit quiet, smooth, vibration-free performance without backlash.

4.1.1.1 Manual Locks

Integrated into the gear box design there shall be a positive, manually operated locking system which will react the maximum torque loads and ultimate structural load directly into the radius arm structure.

4.1.1.2 Output Requirements

a. Speed Range = .25 to 1.67 rpm.

b. Torque - Operating 1.67 rpm. = 3800 in.-lbs.

c. Torque - Holding-input Shaft Locked and Torque Applied at Output With Manual Locks Unlocked = 16,275 in-lbs. (Without Deformation)

d. Torque - Holding - Manual Locks Engaged - =37,750 in-lbs. -(Without Fracture)

c. Input / Output Ratio = 3:1

4.1.2 Transition Gear Box Assemblies

There are two transition gear box assemblies mounted on the upper and lower sides of the radius arm structure. These units shall enable drive shaft routing around the couch clearance envelope, provide additional speed reduction, and house the pivot position control feed back indicators.

4.1.2.1 Output Requirements

a. Speed Range = .75 to 5 rpm.

b. Torque-Operating @ 5 rpm = 1266 in.-lbs.

c. Torque-Holding-Input Shaft Locked and Torque Applied at Output = 5333 in.-lbs. (Without Deformation).

d. Torque-Holding-Input Locked and Torque Applied at Output = 12,583 in.-lbs. (Without Fracture).

e. Input / Output Ratio 6:1

4.1.2.2 Position Indicators

A system of limit switches shall be designed into the transition gear assemblies to indicate the pivot frame position with respect to the centrifuge primary axis.

4.1.3 Distribution Gear Box

The distribution gear box assembly shall be designed for installation on the radius arm support structure and shall provide an interface mounting for the drive motor and transmission system. The unit shall be precision type, providing smooth, quiet, power distribution to the two splined output shafts.

4.1.3.1 Output Requirements

The distribution box shall be designed to meet these requirements simultaneously at each output shaft.

a. Speed Range = 4.5 to 30 rpm.

b. Torque - Operating @ 30 rpm = 21 in.-lbs.

c. Torque - Holding, Input Shaft Locked and Torque Applied at Output = 888.8 in.-lbs (Without Deformation).

d. Input / Output Ratio = 1:1.

4.1.4 Drive Motor and Transmission

4.1.4.1 Drive Motor and Brake Assembly

a. 115V-400 CPS, 3-Phase-AC Type

b. Rated @ 1/3 HP

c. Explosion Proof

d. Reversible

e. Life - 5000 Hr. Continuous Duty

f. Brake Responce - .1-sec-full speed to stop.

g. Brake Holding Torque = 80 in.-oz.

4.1.4.2 Transmission

a. Speed Reduction = 260:1 (Approximate)

b. Sealed Unit - No Contamination Generation Shall Occur, External to the Unit, When Operated in a Chamber at 1psia Atmospheric Pressure.

c. Output - Speeds = 4.5 to 30 R.P.M. Torque @ 30 rpm = 422 in. lbs. min.

d. With the Output Shaft Locked, and the Brake Released, the Unit Shall Withstand the Full Stall Torque of the Drive Motor without Deformation

e. Life-5000 hr. of Operation without Indication of Excessive Wear.

f. Smooth, Quiet Operation with Zero Backlash.

4.2 CONTROL SYSTEM

The Space Research Centrifuge Control Sub-system requirements are defined in the Command and Control Document, SRC-SD-202. The Pivot Drive Sub-system shall be compatible with the requirements defined therein.

4.3 WEIGHT

All elements of the Pivot Drive Sub-system design shall be weight optimized to react only the loads, plus a suitable safety margin, imposed by operation in a zero "g" environment. The additional loads imposed during ground operations shall be compensated for by removable bracing and/or stiffening designed specifically for the application.

4.4 RELIABILITY

The drive sub-system shall, in the finally accepted configuration, meet the minimum reliability requirements applicable to the Man-Rated Space Research Centrifuge Program.

5.0 ACCEPTANCE

Initial acceptance of the drive unit shall be based on the satisfactory demonstration of performance as a unit. The final acceptance demonstration, however will be accomplished with the sub-system integrated with the control system and other elements of the Space Research Centrifuge.

SRC-SD-418

SUB-SYSTEM SPECIFICATION

for the

ROLL DRIVE SUB-SYSTEM

for the

SPACE RESEARCH CENTRIFUGE
ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract No. NAS-1-7309

Prepared by

CONVAIR DIVISION OF GENERAL DYNAMICS
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R. Saunders

Approved J. E. Stumm
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Approved B. D. Newsom
B. D. Newsom, Ph. D.

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1.0 SCOPE

This specification defines the sub-system requirements for the design and development of an integrated motor and drive train unit and a roll frame support system.

1.1 DEFINITION

The basic elements of the roll drive system are as follows.

1. Roll Frame.
2. Pivot Segment.
3. Rotating Support Assembly.
4. Roll Drive Unit.
5. Manual Lock Assembly.

1.1.1 Documentation

The following list of documents shall form a part of this specification.

Roll Drive Sub-system Dwg., SRC-SD-417

Test Requirements - Space Research Centrifuge, SRC-SD-604

1.1.2 Reference Documents

Space Research Centrifuge
General Arrangement Dwg., SRC-SD-110
System Specification, SRC-SD-111
Instrumentation Sub-system, SRC-SD-202

Pivot Segment Dwg., SRC-SD-405

Experimental Program Development for T-010, SRC-MS-112

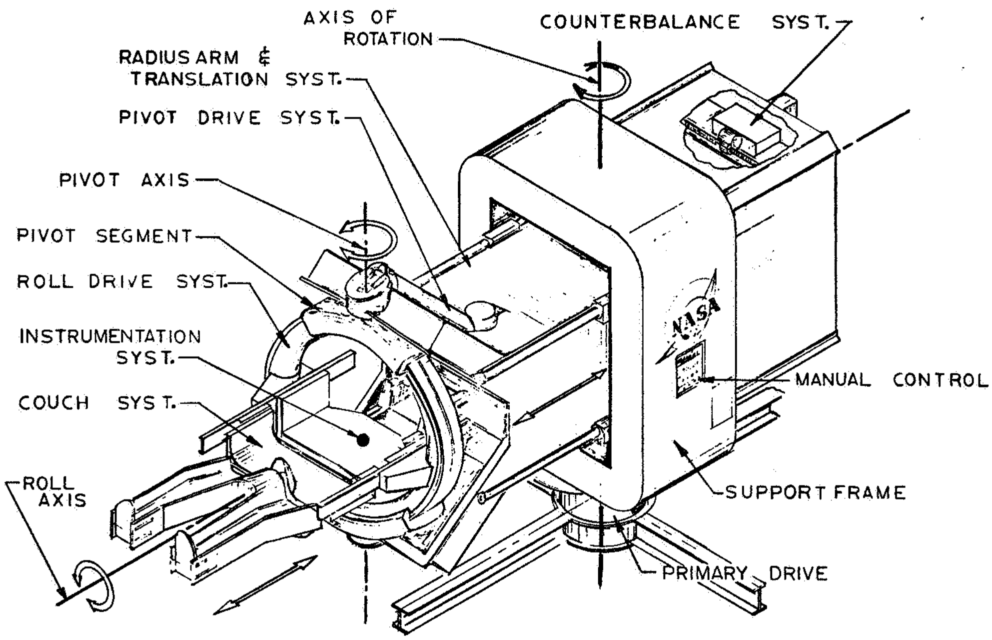
Couch Assembly Dwg., SRC-SD-506

1.2 PURPOSE

One of the proposed experiments to be conducted on the space research centrifuge will evaluate man's threshold levels of sensitivity to angular acceleration. This experimentation requires that the test subject be rotated about his long body axis (Z-axis) with precise variations in rpm being controlled through a computer. The roll drive mechanism will provide this variable rotation capability.

2.0 FUNCTIONAL REQUIREMENTS

The roll drive sub-system shall provide the following functional capabilities.



Ground Based Centrifuge (Reference Figure 1, SRC-SD-111)

2.1 MANUAL OPERATION

Manual control of the roll drive shall be provided to enable positioning of the couch. The couch may be rotated at either fast or slow speeds when in the manual mode with the manual locks disengaged.

2.2 AUTOMATIC OPERATION

When in the automatic mode, the roll drive will respond to a series of random commands from a computer program to accelerate or decelerate as a function of the test subject's response. Automatic operation of the roll system shall be contingent upon the proper alignment of the interlocking system.

2.3 ABORT OPERATION

Abort of an automatic roll drive sequence can be initiated by any one of three conditions:

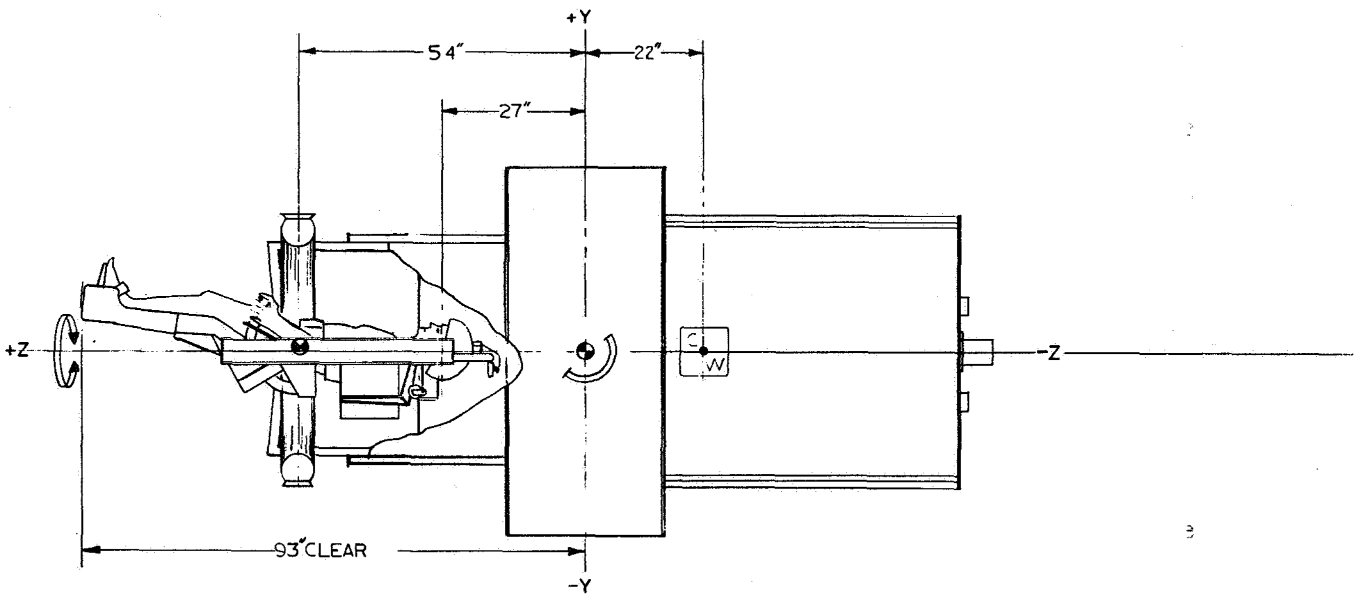
1. test subject aborts
2. test monitor aborts
3. automatic abort.

The first two conditions are self explanatory.

Automatic abort occurs if any of the control innerlock indicators are lost. Activation of an abort will cause the roll drive to decelerate smoothly to full stop.

3.0 PERFORMANCE REQUIREMENTS

With the center of gravity of the couch assembly and test subject located on the pivot axis (Ref. Fig. 2), the roll system shall meet the following performance requirements.



T010C ANGULAR ACCELERATION THRESHOLD

(Reference Figure 4, SRC-SD-111)

3.1 QUIETNESS OF OPERATION

The system shall be designed to provide smooth, quiet, vibration free rotation of the roll frame within the pivot segments.

4.1.2 Pivot Segment and Roller Assembly

Two pivot segments shall be designed to assembly on the roll frame through a system of rollers, which will react the loads imposed on the roll frame during 9 "g" operation of centrifuge, and will also provide for smooth, quiet rotation of the roll frame during "Z" axis rotation.

The pivot segments will also provide the mounting interface between the rotational drive unit and the ring gear in the roll frame.

In the final assembly of the centrifuge the pivot segments will transmit all the couch loads into the radius arm structure through the pivot drive heads.

4.1.3 Drive Unit

The roll drive shall be a sealed unit, assembled onto of the pivot segments. It interfaces with the roll frame ring gear through a Teflon drive pinion. The drive unit consists of the following.

1. Drive Motor

   28V - dc (brushless)
   Fractional hp - variable speed
   Intermittent duty cycle
   Reversible

2. Drive Unit Transmission

   Torque output at drive pinion = .25 in. lbs.
   Output speed range = 12.12 to 48.5 rpm
   Ratio - drive pinion/ring gear 24.25:1
   Integral failsafe mechanical brake
   Digital tachometer

4.1.4 Manual Lock Assembly

On the pivot segment opposite the drive unit there shall be provision made for a manual locking device. The manual lock shall have these features.

1. Lock shall be a positive acting device which is operable with one hand.
2. Remote indications of roll frame locked positions shall be provided.

3.2 POSITION REQUIREMENTS

Positioning of the couch assembly at 0°, 45° and 90° with respect to the pivot axis shall be maintained by a fail-safe mechanical locking system.

3.3 DRIVE UNIT REQUIREMENTS

A variable speed drive motor shall enable rotation in either direction about the couch "Z"-axis, at controlled speeds up to 20 rpm maximum.

3.3.1 The drive sub-system shall be compatible with a 15 psi oxygen environment.

3.3.2 System response shall enable 10 second accelerations, or decelerations, from $0.1^\circ/\text{Sec}^2$ to $3.0^\circ/\text{Sec}^2$.

3.3.3 In response to any abort condition, the drive unit shall decelerate to a full stop over a period of 5 seconds.

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

Configuration of the roll drive system shall be as shown on Dwg. SRC-SD-417 and shall consist of:

1. Roll Frame.
2. Pivot Segment and Roller Assembly.
3. Drive Unit.
4. Manual Lock Assembly.

4.1.1 Roll Frame

The roll frame assembly is composed of a rigid, circular, structural frame to which a peripheral track and ring gear are attached. Mounted to the inner ring, on both sides, are box beam assemblies which provide the mounting interface for the couch assembly.

3. Lock shall withstand the full stall torque output from the roll drive system and the maximum structural loads imposed on the roll frame during the high "g" experiments.

4.2 CONTROL SYSTEM

The over-all control system for the space research centrifuge is defined in the instrumentation sub-system document (Ref. SRC-SD-202).

The roll drive sub-system shall be designed to be compatible with the following basic control elements.

4.2.1 Manual Mode

1. Locked position indicators.
2. Both forward and reverse drive.
3. Emergency stops.
4. Velocity and acceleration readouts.

4.2.2 Automatic Mode

1. Function generator and computer input with response feedback.
2. Velocity and acceleration readouts.
3. Emergency stops.
4. Drive interlocks with the primary rotational drive.

4.3 WEIGHT

All elements of the roll drive sub-system design shall be weight optimized to react only the loads, plus a suitable safety margin, imposed by operation in a zero "g" environment. The additional loads imposed during ground operation shall be compensated for by removable bracing to the maximum extent possible.

4.4 RELIABILITY

The roll drive sub-system in the finally accepted configuration shall meet the minimum reliability requirements applicable to the Man-Rated Space Research Centrifuge program.

5.0 ACCEPTANCE

Initial acceptance of the roll drive sub-system shall be based on the satisfactory demonstration of performance as a unit. The final acceptance demonstration, however, will be accomplished with the sub-system integrated with the control system and other elements of the Space Research Centrifuge.

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SRC-SD-513

SUB-SYSTEM SPECIFICATION

For A

COUCH SUB-SYSTEM

For the

SPACE RESEARCH CENTRIFUGE ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER

Contract NAS-1-7309

Prepared by

CONVAIR DIVISION OF GENERAL DYNAMICS
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1.0 SCOPE

This specification defines the sub-system level of requirements for a one-occupant, adjustable, couch sub-system to be developed as a part of the Space Research Centrifuge Engineering Development Prototype.

1.1 DEFINITION

The centrifuge couch shall be composed of the following elements.

1. Structural Assembly.
2. Position and Restraint Mechanisms.
3. Contoured Body Support

1.1.1 Documents

The following documents form a part of this specification

Couch Assembly - SRC-SD-506

Test Requirements - Space Research Centrifuge
SRC-SD-604

1.1.2 Reference Documents

Space Research Centrifuge
General Arrangement - SRC-SD-110
System Specification - SRC-SD-111
Command and Control Sub-System- SRC-SD-202
Roll Frame Assembly - SRC-SD-514

Experimental Program Development for T-010
SRC-MS-112

Structural Arrangement, Couch SRC-SD-507

1.2 PURPOSE

Test subject positioning requirements, as dictated by the presently defined T-010 experiments, establish that a wide range of adjustment capability be built into the centrifuge couch. The intent of this specification is to develop an initial design for a test subject couch which will meet both the orientation and structural requirements of the Space Research Centrifuge.

2.0 FUNCTIONAL REQUIREMENTS

The Couch Sub-System shall be designed for the following.

2.1 SIZE

The couch shall be designed for one man occupancy in a shirt sleeve environment, and shall provide sufficient adjustment to accommodate a test subject variation from 25 to 75 percentile.

2.2 OPERATION

All couch manipulation and adjustment devices shall be manually operable by a single person without the use of tools.

2.3 INTERFACES

The couch design shall be compatible with the centrifuge roll frame support bracketry and shall interface with the command and control sub-system through a detachable connector.

3.0 PERFORMANCE REQUIREMENTS

With the couch integrated into the centrifuge system,the following performance capabilities shall be met.

3.1 GENERAL OPERATION

Operation of the positioning devices shall be smooth, quiet, free of chatter and rigidly guided. All rubbing surfaces shall be fabricated of materials which are mutually compatable with dry operation.

3.2 POSITION REQUIREMENTS

The following body positioning capabilities shall be provided.

1. Test subject head position shall be fixed with respect to the couch frame. Body variations shall be accommodated for by variation of the hip hinge point and the foot rest restraint.
2. Test subject's legs shall be adjustable to three fixed positions.

    a. Prone

b. Mid-position (tilt table condition, Ref. SRC-MS-112).

c. Semi-sitting, legs up.

3. Head movements shall be controlled by a restraint helmet which will permit either pitch or yaw movement with respect to the long body axis. A restraint lock shall rigidly hold any preset position in either pitch or yaw and still allow free movement in the unlocked plane.

4. Test subjects shall have free movement of their hands and arms except that suitable handles shall be provided to enable subject restraint during high "g" experimentation.

3.3 STRUCTURAL

The structural elements of the centrifuge couch shall provide sufficient stiffness and structural integrity to react the combined centrifugal and inertial loads resulting from any of the presently defined T-010 test series, (SRC-MS-112).

3.4 EMERGENCY OPERATION

All restraint systems shall have a positive acting, quick release capability. The release mechanism, however, shall not be of a type which can be released inadvertently.

4.0 DESIGN REQUIREMENTS

4.1 CONFIGURATION

Drawing - SRC-SD-506 defines a baseline configuration for the Space Research Centrifuge Couch Sub-System. The primary elements of the sub-system are:

1. Structural assembly.

2. Position and Restraint Mechanisms
3. Contoured Body Supports
4. Experiment Attachements

4.1.1 Structural Assembly (REF. SRC-SD-507)

The couch structure is composed of two channel shaped rails, between which are mounted the upper and lower body support beams.

Affixed to the upper body support beam is the head restraint and test subject helmet assembly.

Attached to the lower body support beam is the saddle and leg support structure, which provides lower body structural support.

All elements of the support structure shall be capable of withstanding the combined effects of the man/machine loads resulting from a rotational "g" environment of 9 "g". A safety factor of 1.5 shall be applied to all couch structure.

4.1.2 Position and Restraint Mechanisms

All positioning devices shall be positive acting with dual locking of each set position. The mechanisms shall operate dry.

4.1.2.1 Couch Translation

The couch side rails shall interface with the roll frame mounting bracketry to provide a 27 inch translatory adjustment capability. (Ref. SRC-SD-110)

4.1.2.2 Hip Adjustment

The hip hinge attachment to the main couch support frame shall be adjustable over a 3 inch stroke to compensate for varing test subject body sizes.

4.1.2.3 Leg Positions

Three leg positions shall be provided, 25^{o}, 53^{o} and 81^{o} from the test subject's "Z" axis center line.

4.1.2.4 Leg Adjustment

The foot restraint mechanism shall provide for a 6 inch variation in test subject leg length.

4.1.2.5 Head Restraints

In both the yaw and pitch directions, the head restraint system shall have $\pm 35^{o}$ of adjustment capabilities. Also, incorporated into the head restraint system, there shall be an instrumentation device which will provide a remote readout of the test subject's head movements.

4.1.3 Contoured Body Supports

The test subject couch shall be provided with a contoured couch padding system which will provide uniform support of the test subject and will appropriately distribute the subject's body loads into the couch frame.

The padding system shall be designed to be compatible with the couch/man adjustments.

4.1.4 Experiment Attachement

A provision shall be made in the couch design to allow for the attachment of various experiment oriented test equipment (Ref. SRC-SD-202). Attachment shall include, but not be limited to, the following.

1. TV Monitoring Camera.
2. Biomedical Instrumentation
3. Physiological Instrumentation
4. Emergency first aid kit, including emergency air supply.
5. Emises collection device.
6. Voice communication system.

4.2 CONTROL SYSTEM

The Space Research Centrifuge Control Sub-System requirements are defined in the command and control document, SRC-SD-202. The couch system shall be compatible with the requirements defined therein.

4.3 WEIGHT

All elements of the couch sub-system design shall be weight optimized to react only the loads, plus the required safety margins, imposed by operation in a zero "g" environment. The additional loads imposed during ground operation shall be compensated for by removable bracing to the maximum extent possible.

4.4 RELIABILITY

The couch sub-system in the finally accepted configuration shall meet the minimum reliability requirements applicable to the Man-Rated Space Research Centrifuge Program.

5.0 ACCEPTANCE

Initial acceptance of the couch sub-system shall be based on the satisfactory demonstration of performance as a unit. The final acceptance demonstration, however, will be accomplished with the sub-system integrated with the control system and other elements of the Space Research Centrifuge.

TEST REQUIREMENTS

For the

SPACE RESEARCH CENTRIFUGE
ENGINEERING DEVELOPMENT PROTOTYPE

LANGLEY RESEARCH CENTER
Contract NAS-1-7309

Prepared by

CONVAIR DIVISION OF GENERAL DYNAMICS
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1.0 GENERAL

This document establishes the testing, test procedure development and reporting requirements of the ground based, engineering development, prototype of the Space Research Centrifuge (SRC) described by SRC-SD-111.

1.1 SCOPE

The objective of this series of tests shall be the provision of a basis for verification and acceptance of SRC systems and experiments throughout their development. Tests shall be identified according to the following classification.

a. Preliminary Development Tests

b. Acceptance Tests

c. Evaluation Tests

d. Flight Experiment Support Demonstration.

1.2 TEST PROCEDURES

A comprehensive test procedure shall be prepared for each test required by this document. The test procedure shall describe the test set-up; identify all essential test equipment; specify safety procedures where applicable; specify the test method (i.e., number of cycles, rate, time, acceleration, loads applied, environmental condition, etc.) state the parameters to be measured and the limits of such measurements which constitute acceptance.

Procedures for tests of a development nature, such as specified by Section 2.0, shall be submitted to NASA for review prior to the start of testing.

Procedures for acceptance and performance verification shall be reviewed and approved by NASA prior to the start of testing. Such testing shall be witnessed by the NASA program office coordinator or his designee.

1.3 TEST REPORTING

The results of all test activities shall be documented in formal test reports and submitted to NASA within 30 days of test completion.

Reporting shall be accurate and complete for the purpose intended. Where data is offered in evidence of compliance or performance verification, test observers' notes, oscillograph traces, recording tapes, etc. shall be reproduced directly, without transcript or redrawing. All acceptance test reports shall require the approval of the NASA Program Office as a condition of acceptance.

2.0 PRELIMINARY DEVELOPMENT TESTS

Preliminary development tests shall be performed to determine the performance of critical subsystems and components prior to their incorporation in the SRC. Such testing shall include those tests described by Section 2.1 through 2.4 and shall be performed prior to or concurrent with detail engineering design.

2.1 CONTROLS AND COMMUNICATIONS

Breadboard control system circuits shall be assembled which are representative of the primary drive control, counterweight control, translation arm control, couch pivot control, couch roll drive control and counter-momentum control systems. In addition, breadboard assembly of the test subject/monitor communications system shall be made including both RF (Antenna) and rotary capacitor links. Preliminary evaluation of these systems shall be made prior to packaging for SRC installation.

2.2 DRIVE MOTOR

Tests shall be performed to evaluate the operating characteristics and systems requirements of the main drive motor prior to its incorporation in the SRC. A test fixture shall be developed which is suitable for installation of the motor or motors under consideration. Provisions shall be made for duplication of the inertial, friction and windage loading characteristics of the centrifuge and for application of specific torque loads in determinig torque/speed and acceleration characteristics. The motor test fixture shall be integrated with the primary drive control breadboard specified by Section 2.1. The electrical, acoustic, thermal and mechanical behavior of the motor shall be determined for conditions of maximum/minimum acceleration and braking, start-up and shut-down transients, and for all off-design conditions which may be imposed by the single failure of any system or control component.

2.3 BEARINGS AND LUBRICATION

Preliminary evaluation of bearing and lubrication systems for the SRC shall be made. Bearing systems to be tested shall include the Main Drive bearing, the Pivot Hub bearing, the Roll Frame bearings and the Radius Arm Translation Ball Screw. A test fixture shall be assembled which allows each of the bearing systems specified to be loaded and driven in a manner duplicating operating conditions in both the ground based application and the flight experiment application. For the ground based operating condition, bearings shall be assessed for efficiency, wear, heat dissipation, and noise and vibration generation. For the flight operating condition, tests shall be performed in an oxygen atmosphere of 6 $\pm$ 1 psia and contaminant generation added to the list of observed phenomena. In addition, the effects of launch acceleration and vibration loads shall be assessed using Saturn IB booster data as a characteristic model.

2.4 ANTHROPOMETRIC INTERFACE

Tests evaluating the interfaces between the centrifuge, the test subject and the test monitor shall be performed using an accurate mock-up of the interface area. The mock-up shall include the test subject's couch and instrumentation, the roll frame and the translation arm jaw area. In addition, the monitoring and control panel shall be realistically represented.

The centrifuge mock-up shall serve to evaluate clearances for all couch positions, couch fit and comfort, location of instruments, adjustments, locks, restraints, harnesses, hand holds, and local lighting.

The control and monitoring panel mock-up shall allow evaluation of the visibility of test subject status, placement of controls for normal operation and emergency reaction, and sequence and time requirement of set-up operations.

The mock-up shall be the subject of a review and demonstration involving flight experienced astronauts, principle investigators and NASA Program Office representatives. The NASA Program Office shall be the final arbiter of all change requests resulting from such a mock-up review. A second review shall be scheduled after incorporation of authorized changes.

2.5 INSTRUMENTATION INTERFACE

The "Integrated Medical and Biological Laboratory Measuring System" (IMBLMS) currently under development will be examined to insure that the centrifuge monitoring requirements are compatible with the established space hardware. The IMBLMS will be used as a GFE item and the SRC data collection system adjusted as required. Requirements not covered by the existing measurement system will be called out for further IMBLMS development or made as an additional requirement to be included in the SRC system.

3.0 GROUND BASED CENTRIFUGE ACCEPTANCE TESTS

A series of acceptance tests as outlined in this section shall be performed at the contractor's facility as proof of compliance to the design and performance requirements of SRC-SD-111 and to establish the unit as a safe and representative prototype of the flight centrifuge. These tests shall be performed in total prior to the tests of Sections 4.0 and 5.0. In the event of redesign or modification of the unit as a result of continued development, those tests or portions of tests affected shall be repeated prior to contract completion. Where such redesign or modification affects the safety of the test subject, recertification shall be required before tests which may compromise the test subject are performed. Such interim recertification shall be performed at the direction of the program safety officer.

3.1 CONFORMANCE TO ENGINEERING DESIGN

The identification and location of all equipment shall be checked against assembly drawings and related engineering coverage. Overall dimensions of the unit shall be verified. Measurement of the mass and maximum moment of inertia of the complete centrifuge assembly representative of the flight hardware shall be made. The motion envelope provided by the couch (adjustment and leg position) head restraint, couch translation, roll system, pivot system, radius arm translation and perturbation systems shall be demonstrated as meeting design requirements. The counterweight system shall be driven through its full range of travel. Applicable tests may be combined with those of Section 3.2.

3.2 PROOF LOADING

Static proof loads shall be applied to all load bearing structure and mechanisms prior to operation of the centrifuge. Structural elements shall be subjected to 1.25 times the maximum operational load anticipated. Load bearing mechanisms shall be subjected to 1.50 times the maximum operational load anticipated. No permanent deformation or performance degradation shall result from the application of such loading. Appropriate static proof loads shall be applied for all operational positions of the centrifuge couch and arm.

3.3 FUNCTIONAL CHECK-OUT

A series of qualitative operational tests shall be performed on all centrifuge systems. This shall include the following:

a. Operation of all locks, interlocks, safeties and detents.

b. Head position indication

c. Voice communication between test subject and monitor.

d. Biomonitoring equipment function including pulse rate, blood pressure, respiration rate, skin temperature and mean "g" indicator.

e. Visual communication.

f. Abort control operation.

g. Radius arm positioning system operation and indication.

h. Pivot system operation and position indication.

i. Roll system operation and indicator function in manual and automatic mode.

j. Primary drive start-up, operation and shut-down in automatic and manual mode.

k. Counterweight system operation and position indication in manual and automatic mode.

l. Mass measurement sensor operation and indication.

m. Perturbation system operation.

3.4 PERFORMANCE CHARACTERISTICS

A series of tests shall be performed which demonstrate the gross performance characteristics of centrifuge systems in compliance with the requirements of SRC-SD-111. For these tests, an anthropomorphic dummy with appropriate weight distribution shall occupy the test subjects couch.

3.4.1 Roll System

The couch roll system shall be operated in manual mode to demonstrate positioning ability. Measurements shall be taken of acceleration history, high and low angular rate and position increment threshold. Automatic mode operation shall be evaluated by applying a typical angular acceleration test sequence through the function generator. Position rate and acceleration data as a function of time shall be measured and compared with tape command inputs. Vibration and accoustic clewing resulting from roll system operation shall be assessed.

3.4.2 Main Rotation Drive.

The main rotation drive shall be operated in manual mode with the test subject's couch in the maximum radial position. Acceleration and angular rate time histories shall be measured from zero starting rate to final rates of 10, 20, 30, 40, 50 and 60 rpm. Final rates shall be measured and compared with selected rates. In the automatic mode, tapes representative of greyout and re-entry test sequences shall be used to program the unit and actual acceleration and angular rate time histories measured and compared with programed commands. With the couch in the re-entry test position, the maximum design angular rate shall be applied and held for two minutes. Abort system operation from this condition shall be demonstrated.

3.4.3 Perturbation System

The Frequency response capability of the perturbation system shall be demonstrated over the range of zero to 5 cps. The amplitude ratio of output/input shall be linear within - 3 db from zero to 3.5 cps.

3.5 CYCLIC OPERATION

A sufficient number of cyclic operations of the centrifuge systems shall be performed to assure that no undue wear or rapid degradation is occuring. Cyclic operation shall include:

a. Head Position - Twenty five cycles in each axis, each cycle consisting of unlocking, nodding or turning through the maximum travel and relocking the device.

b. Leg Position - Twenty five cycles, each cycle consisting of unlocking, advancing the leg position and relocking through each of the three leg positions.

c. Couch Translation - Fifty cycles, each cycle consisting of unlocking, travel through the maximum envelope and relocking.

d. Couch Roll - Fifty cycles, each cycle consisting of unlocking, rotation of 5 revolutions clockwise, rotation of 5 revolutions counterclockwise and relocking.

e. Couch Pivot - Fifty cycles, each cycle consisting of unlocking, motion through the maximum envelope and relocking.

f. Radius Arm Translation - Fifty cycles, each cycle consisting of unlocking, translation and relocking at each arm position from minimum to maximum radius and return

g. Main Rotation - Fifty cycles, each cycle consisting of startup, acceleration up to 60 rpm, deceleration and shutdown.

h. Balance System - Fifty cycles, each cycle consisting of radial motion of the counterweights from minimum radius to maximum and return followed by transradial motion from one side to the opposite and return.

i. Perturbation System - Fifty cycles, each cycle consisting of full extension and then full retraction of each actuator set at a rate of 0.2 cps folfowed by one minute of small amplitude excursion at 3.5 cps.

All bearings, bearing surfaces and power transmission elements shall be inspected for surface deterioration, roughness, sticking, looseness, and other signs of deterioration at the completion of cyclic operation.

3.6 SAFETY CERTIFICATION (MAN RATING)

A Safety Certification Board shall be appointed for the purpose of man-rating the ground based prototype unit, assuring test subject and operator safety during subsequent testing and evaluating the safety aspects of the eventual orbital experiment. The Safety Certification Board shall consist of the program safety officer, a medical representative and an engineering representative. The medical representative shall be a licensed physician. It shall be the responsibility of the certification board to review engineering design and specifications and the results of the acceptance testing so as to certify the prototype machine for manned occupancy. Subsequently, review and approval of safety and emergency provisions of test procedures for the tests involving manned occupancy shall be required.

4.0 EVALUATION TESTS

4.1 DETAIL PERFORMANCE.

Evaluation tests shall be performed to investigate operational and performance characteristics of the centrifuge and to provide data pertinent to its spacecraft installation and integration. These tests shall include the following.

4.1.1 Structural Dynamics

The mass distribution and inertial properties of the centrifuge shall be determined for all positions of the couch and arm. Static deflection under load and natural frequency shall also be determined as a function of couch and arm position.

4.1.2 Primary Rotation Drive System.

Dynamic characteristics of primary rotation, such as frequency response, threshold and dead band shall be determined. Abort system response and braking times shall be evaluated for various levels of rotational velocity. Power requirements, efficiency and electrical load characteristics shall be determined. Heat rejection and other thermal characteristics of the drive system shall be evaluated. Quantitative measurements of the acoustic noise generated by the drive shall be made.

4.1.3 Radius Arm Translation System.

The dynamic characteristics of the translation system shall be determined, including frequency response, threshold and dead band. Efficiency and power requirements shall be established. Adequacy of interlocks and stops shall be evaluated.

4.1.4 Couch Pivot System

The dynamic characteristics of the pivot system shall be determined, including frequency response, threshold and dead band. The positioning accuracy of the system shall be established. Power requirements and efficiency shall be determined. Adequacy of detents and interlocks shall be evaluated.

4.1.5 Couch Roll System

The dynamic characteristics of the couch roll system shall be determined, including frequency response, threshold and dead band. Accuracy of the rate and acceleration control shall be established. Efficiency and power requirements shall be determined. Noise generation and other effects providing acceleration clewing shall be quantitatively measured. Adequacy of latches and interlocks shall be evaluated.

4.1.6 Communications and Data Collection

Tests shall be performed which evaluate the detail performance of the communication and data collection systems. This shall include evaluation of voice communication for fidelity and clarity; adequacy of TV imaging and lighting; noise, signal attenuation and other transmission characteristics of all data channels; and performance of data recording and display equipment. Radio frequency interference and electro magnetic interference tests shall be performed and evaluated against the requirements of MIL-I-26600

4.1.7 Counterbalance System

The dynamic characteristics of the counterbalance system shall be determined, including frequency response, threshold and deadband. The amount of residual unbalance shall be measured for each experiment operating condition. The effect of spacecraft motion on the performance of the counterbalance system shall be examined with the use of the perturbation system. Efficiency and power requirement of the system shall be determined.

4.1.8 Mass Measurement System

Accuracy of the mass measurement system shall be determined. The influence of spacecraft motion on the performance of this system shall be evaluated.

4.2 SAFETY AND RELIABILITY

The safety of the test subject shall be evaluated under circumstances imposed by the single failure of any control element, lock or detent. The ability of the test subject to abort the experiment and remove himself from the couch without assistance shall be evaluated for all positions of the couch and arm. Time and motion tests shall also be performed with respect to reaching and reviving or removing an unconscious test subject for any position of the couch and arm. A log of system and component operational history shall be maintained throughout the development as an aid to reliability assessment.

4.3 ANTHROPOMETRIC INTERFACE

All areas of interface between the test subject, the centrifuge and the monitor which were developed by the use of mock-up techniques shall be validated using the flight prototype centrifuge.

4.4 MAINTAINABILITY

Tests shall be performed to evaluate the maintainability of the centrifuge with respect to inspection, servicing and replacement of critical components for both ground based and orbital operation. Access to all areas containing equipment shall be demonstrated.

4.5 EXPERIMENT DEVELOPMENT

Each T-010 experiment procedure will be completed according to protocol with an instrumentated manikin first to determine operational capacity of the control system. Following system verification a subject will be exposed to the experiment procedure and then interrogated for subjective evaluation of the test. The experiment protocol will then be augmented to improve operation and test procedure.

5.0 FLIGHT EXPERIMENT SUPPORT DEMONSTRATION

5.1 PROCEDURAL TRAINING

Tests subjects with learning and performance ability similar to astronauts will be trained on operation of the centrifuge. A study will be made of the control problems that result when naive operators are trained. The analysis will be used to simplify the problem areas with the objective of decreasing training time and chance of error.

6.0 GEO-BASELINE DATA DEVELOPMENT

Following the completion of engineering design tests the centrifuge will be used to determine the subject reaction to a series of experiments under one-g conditions. The experiments which can be expected to produce results most comparable to that of the space experiments are those where the stimulus is angular acceleration rather than imposed g force. For other experiments, the couch must be aligned with the resultant vector of the g and centrifuge acceleration. This can be accomplished by a 90° rotation of the yoke assembly which supports the pivot segments (Ref. Dwg. SRC-SD-109, 3) and will be done only for those tests where angular acceleration or cross coupling is not a primary measurement. Such tests may demonstrate that some experiments should be done at g levels greater than one in space so that Geo-baseline data are comparable.

6.1 EXPERIMENT ACCUMULATION

All of the proposed T-010 experiments will be accumulated for review and possible inclusion in the program. From the selected experiments, an arbitrary number will be chosen to use in the Geo-baseline program. Final decisions on experiment selection shall be made by the technical monitor in accordance with cost and time estimates for program development. The chosen experiments will then be detailed in the form of procedures and protocol requirements for both space and Geo-baseline testing.

6.2 EXPERIMENT TIME REQUIREMENT

Each accepted experiment will be individually developed by a crew and the responsible investigator for that test program. Several of those will be developed simultaneously to conserve time. The experiments will be practiced and repeated until a constant time for completion is reached. This time is to be realistic and representative of the actual testing - not a facsimile of the test period. A time line will be made for each accepted test that includes the training required for the non-scientist type astronauts. The adequacy of the results obtained will be expressed in terms of data distribution.

6.3 ADEQUACY OF EXPERIMENT PROTOCOL

A review of the preliminary test results will be made by an experiment review board which shall include the contract manager, T-010 principal investigator and the responsible experiment investigator. The adequacy of the experiment and the protocol is to be determined, and any necessary changes shall be approved by this board.

6.4 SIMPLIFICATION OF TRAINING REQUIREMENTS

After completion of all preliminary experiment testing, the revised protocols will be reviewed and the common elements for crew training will be extracted. A training document will then be prepared for the T-010 experiments. This document will then be reviewed for the training time required. An assessment of the practicability of time requirement will then be made and coordinated with the MSC personnel cognizant of program training.

6.5 DATA STORAGE, DUMPS AND RETRIEVAL

Personnel specialized in data handling will review the adequacy of the data transmission procedure and adjust the experiment protocol for any insufficiencies.

6.6 DATA REDUCTION AND ANALYSIS METHOD

The acquired information derived from the preliminary testing will be analyzed in the method outlined by the protocol. Distribution of data points will be analyzed for experiment variability and the adequacy of the data reduction method demonstrated. A review of all procedures will be made to determine incidence of transfer error and possible factors that may invalidate the data from the space experiment.

6.7 EXPERIMENT ELIMINATION

The preceding tasks will be organized into report form and submitted to NASA with recommendations for reductions, simplification and/or expansion for those experiments reviewed. Experiment selection will be made on the basis of the crew time allotment that then appears feasible as defined by NASA.

6.8 T-010 PROGRAM INTEGRATION

Experiments will then be rated by importance with respect to (1) advanced mission planning, (2) zero-g crew support and (3) contribution to advanced knowledge. Those showing the highest rating in each category will then be examined for compatibility and possible integration for the greatest efficiency in time and equipment utilization.

A suggested program will then be proposed to NASA, LRC that has been derived from the preceeding baseline study.

6.9 GEO-BASELINE DATA

Acceptance of a T-010 program will then be followed by an advvanced phase of testing using astronaut personnel. For this advanced phase, the SRC will be transferred to a NASA facility for application in final crew training. The acquisition of baseline data on the crew, backup crew, and if possible a dditional astronauts to enlarge the statistics for baseline values resulting from the ground baseline studies.

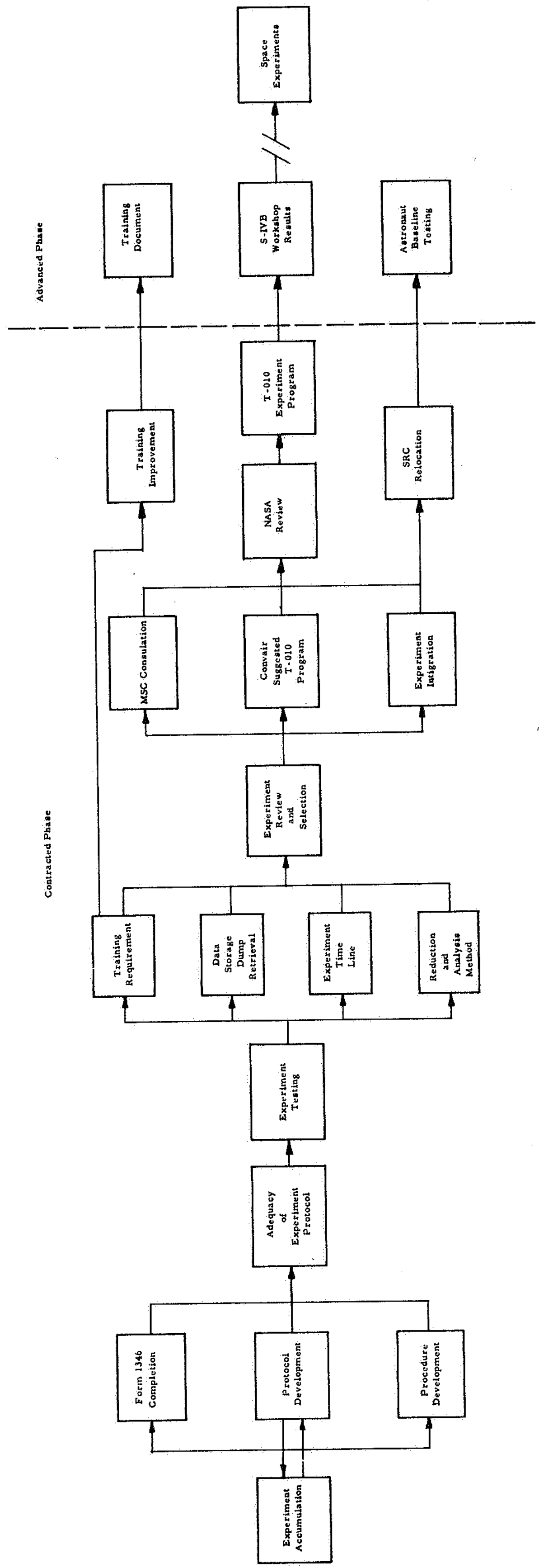
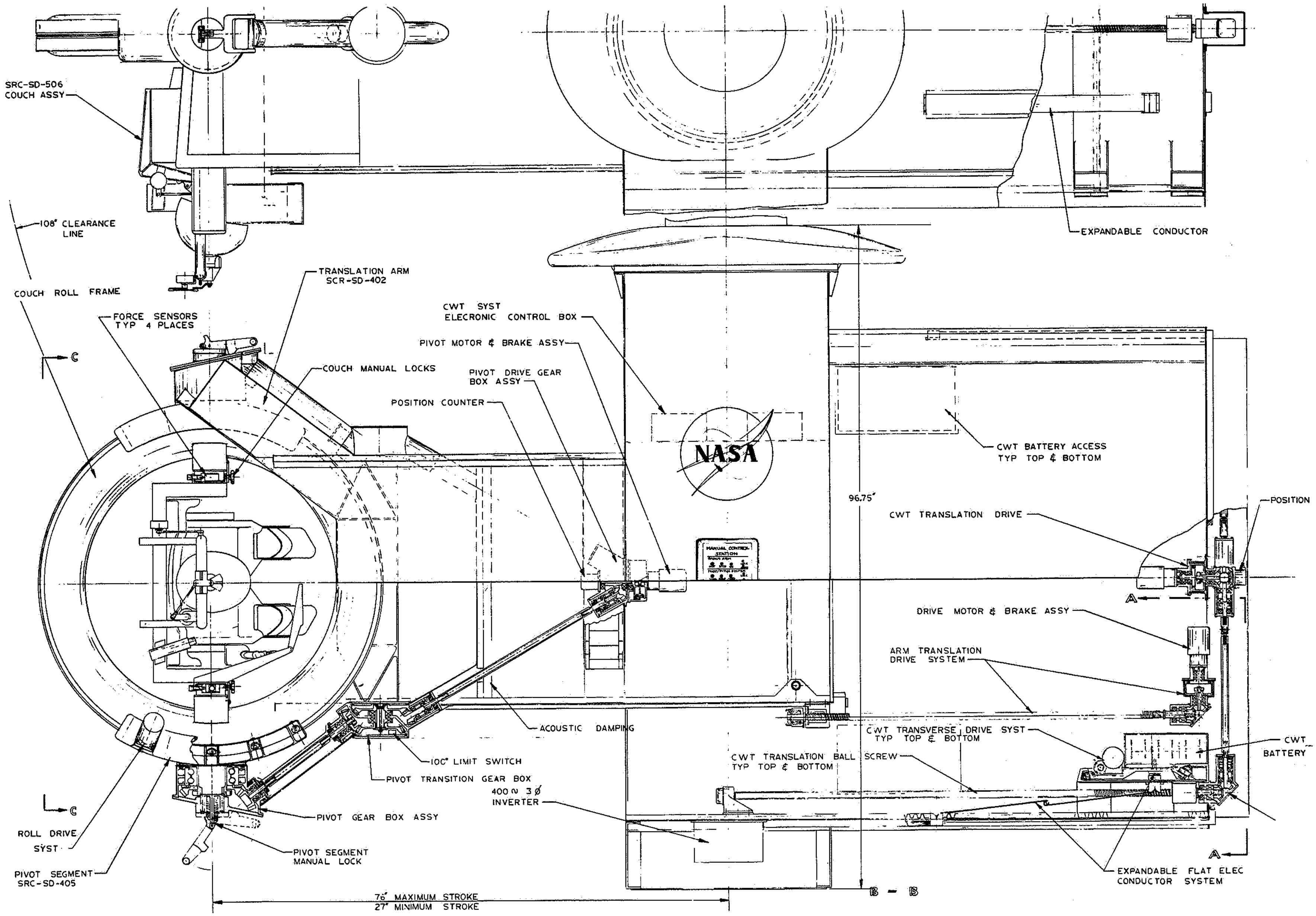
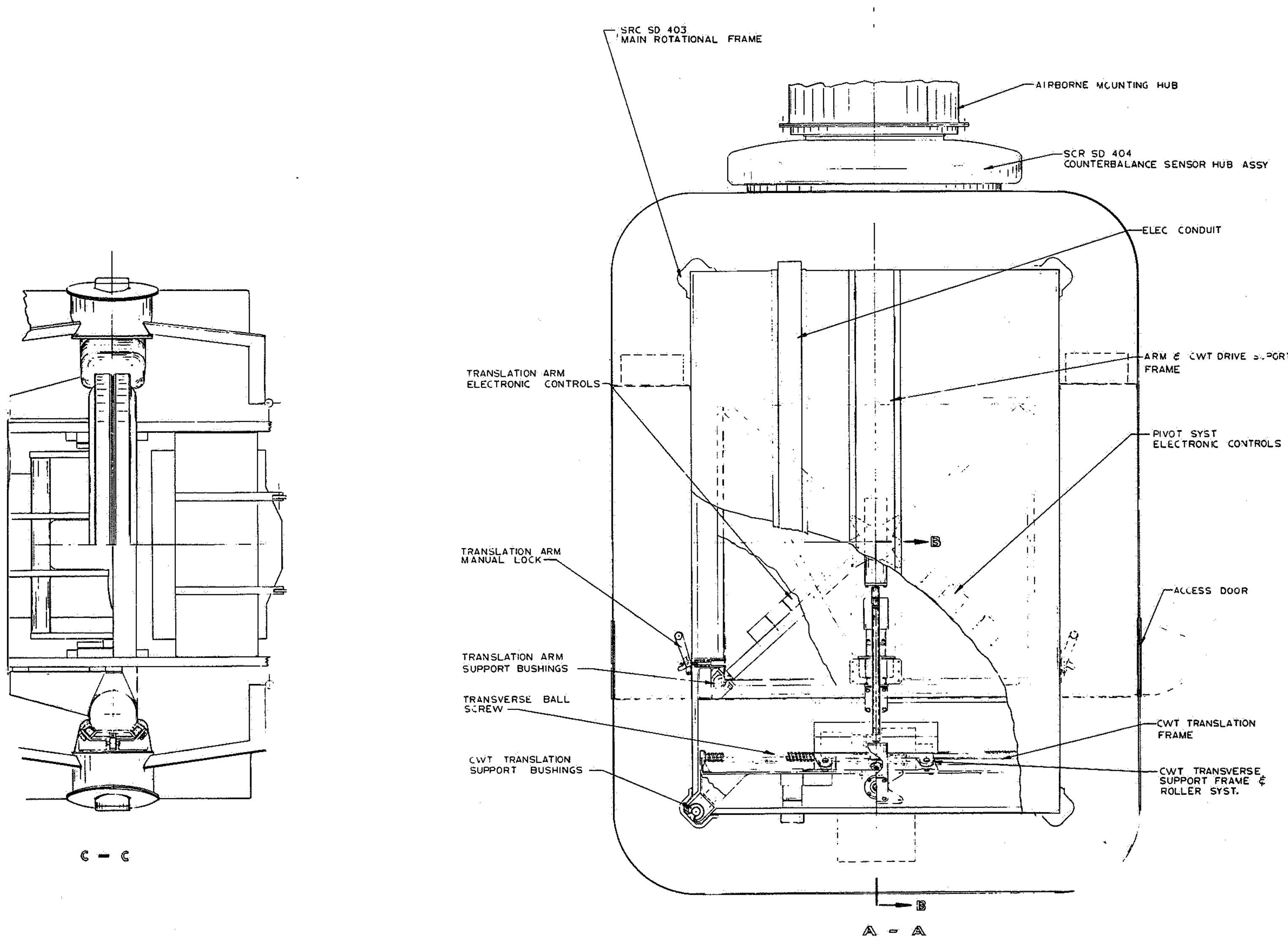


Figure 1. T-010 SRC Ground Test Experiment Program

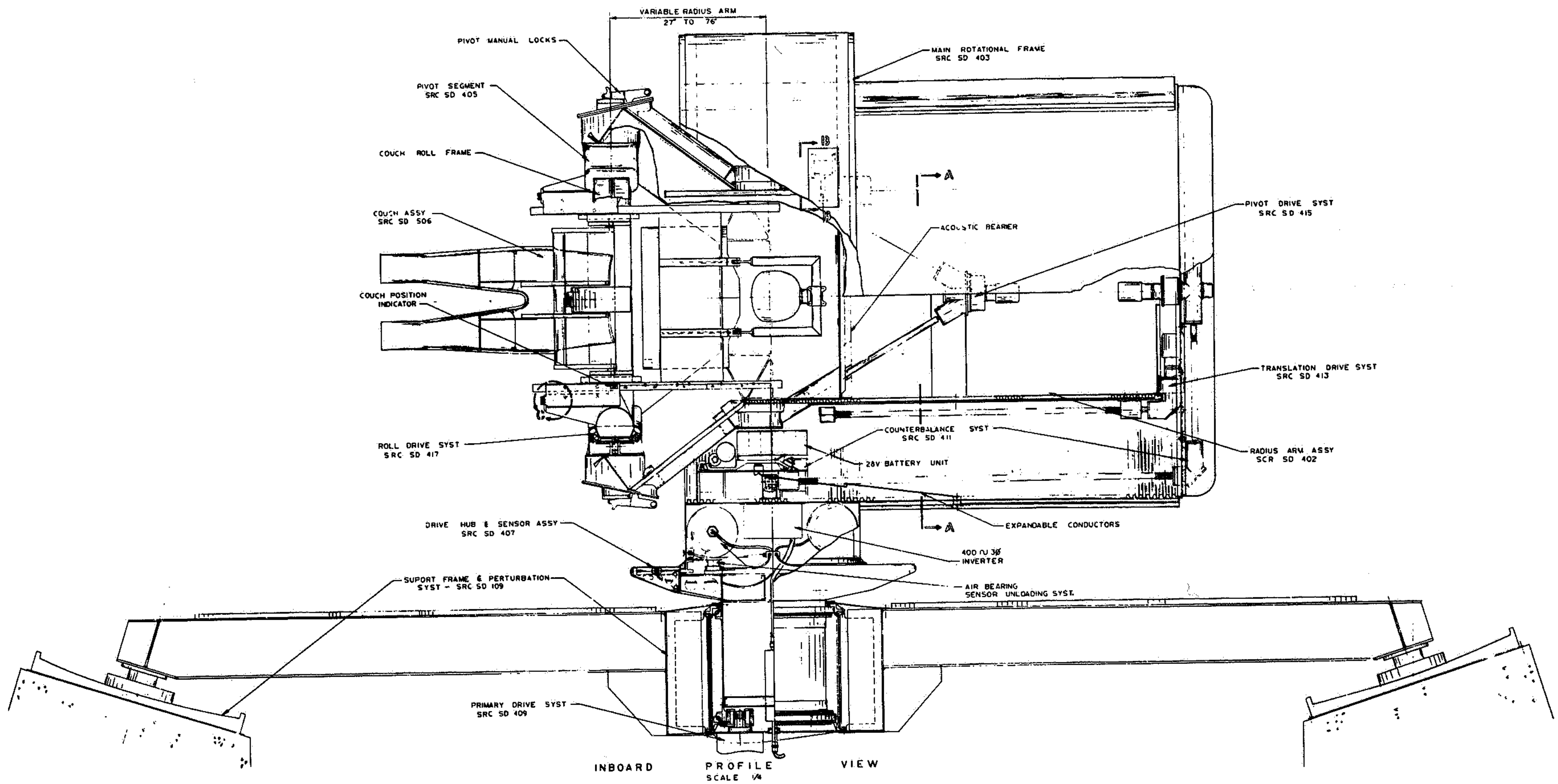
SPECIFICATION DRAWINGS



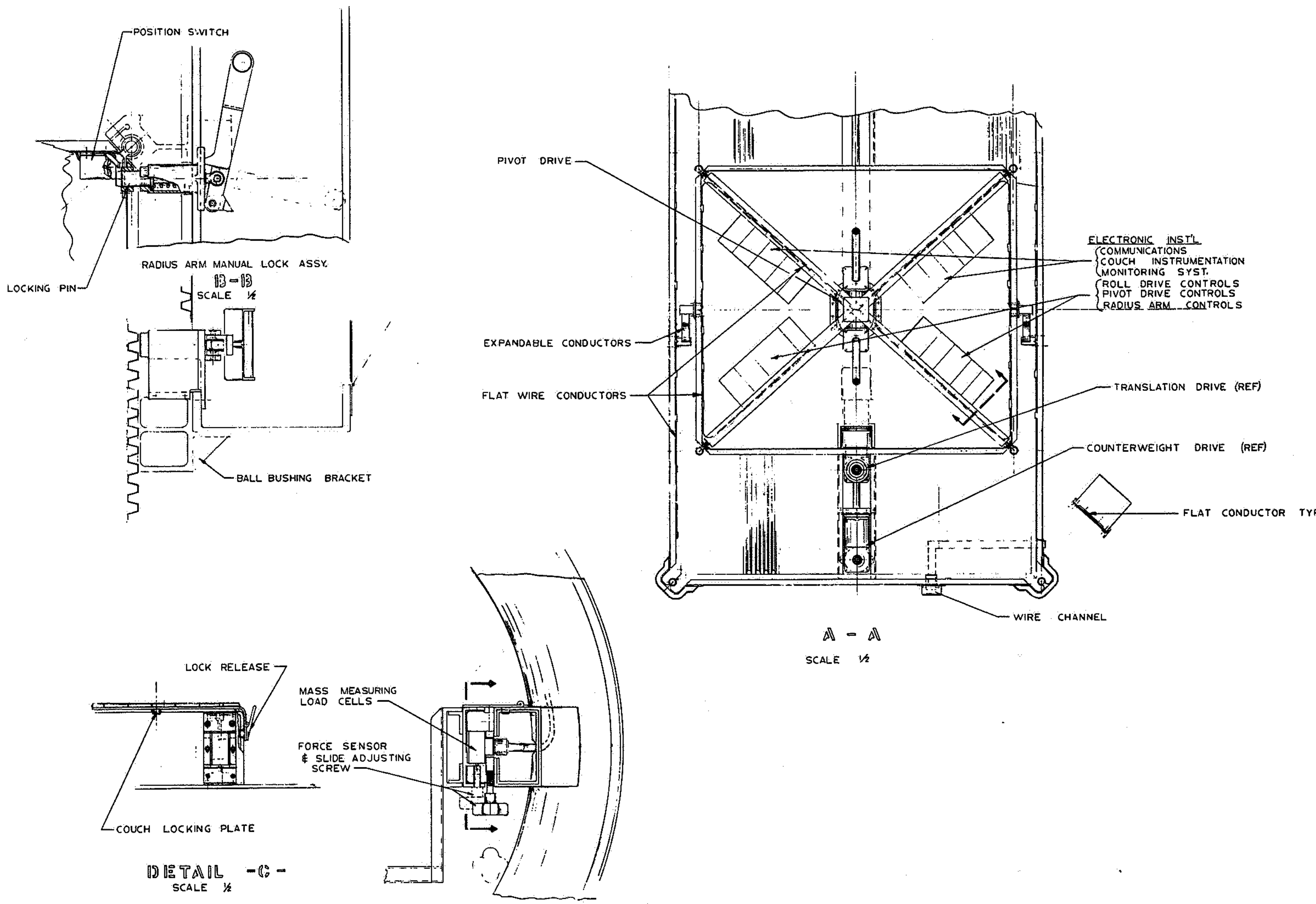
Drawing SRC-SD-106, 1. General Arrangement - Space Research Centrifuge. (Flight Configuration)



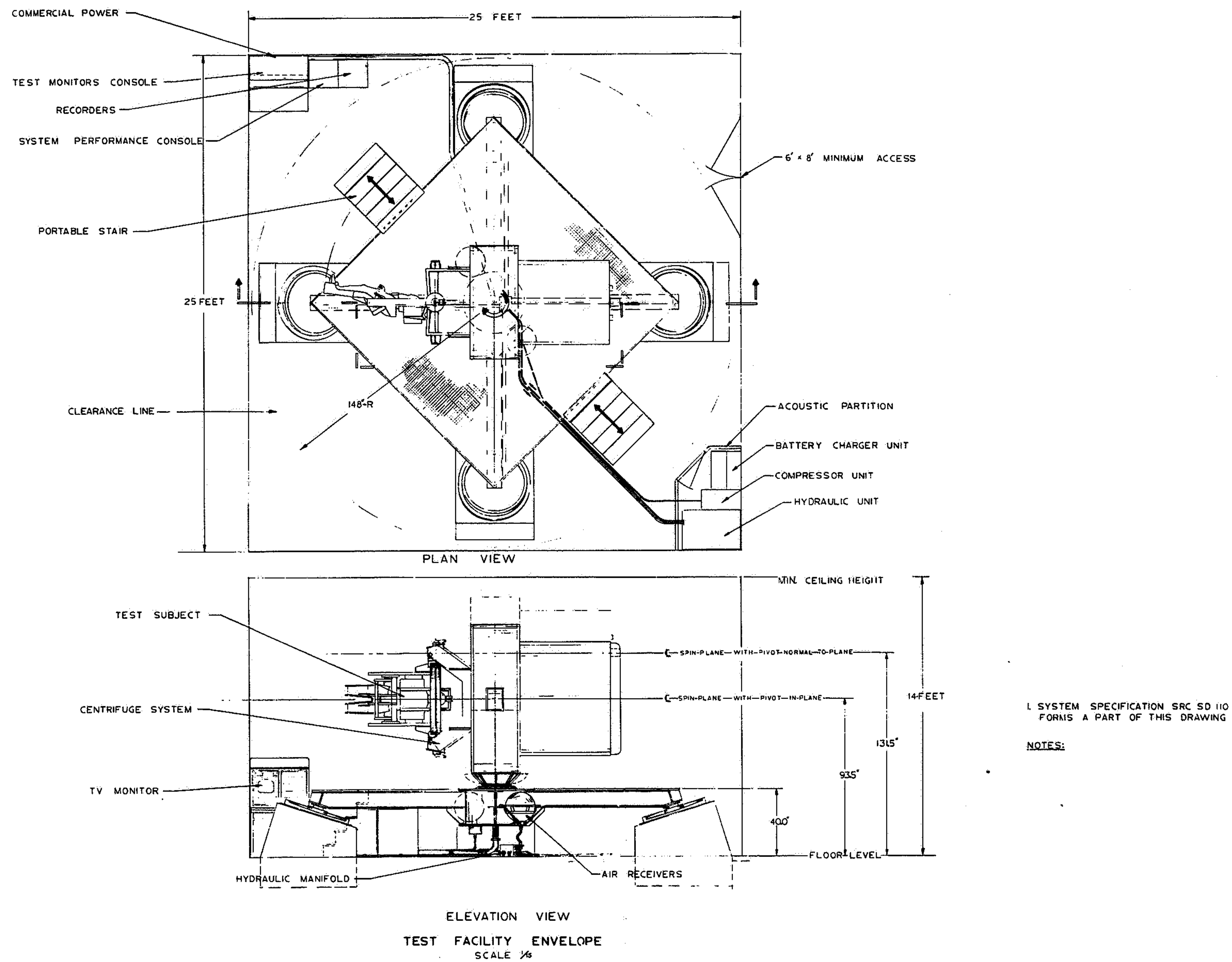
Drawing SRC-SD-106, 2. General Arrangement - Space Research Centrifuge. (Flight Configuration)



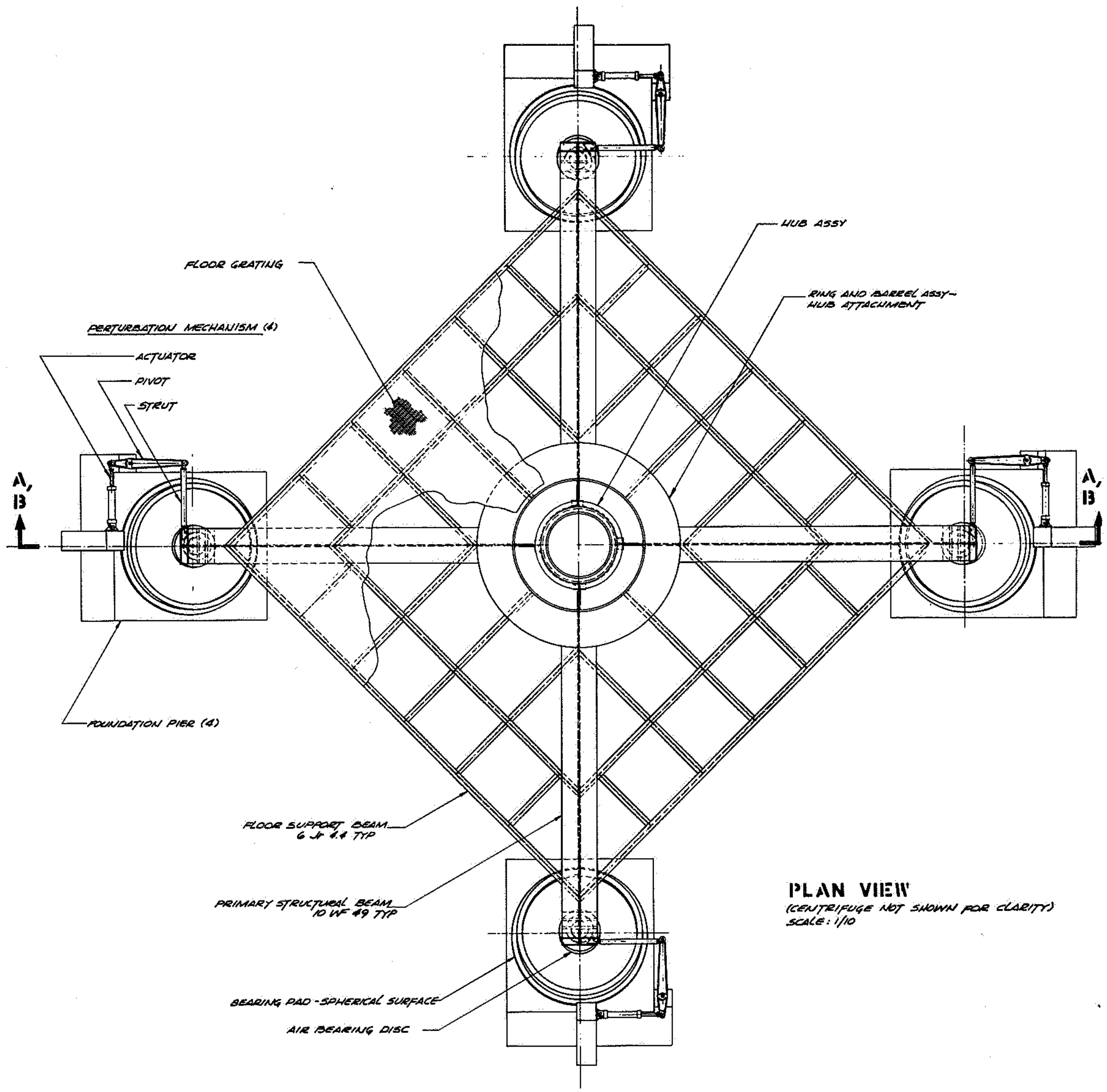
Drawing SRC-SD-110, 1. General Arrangement - Ground Based Prototype Space Research Centrifuge.



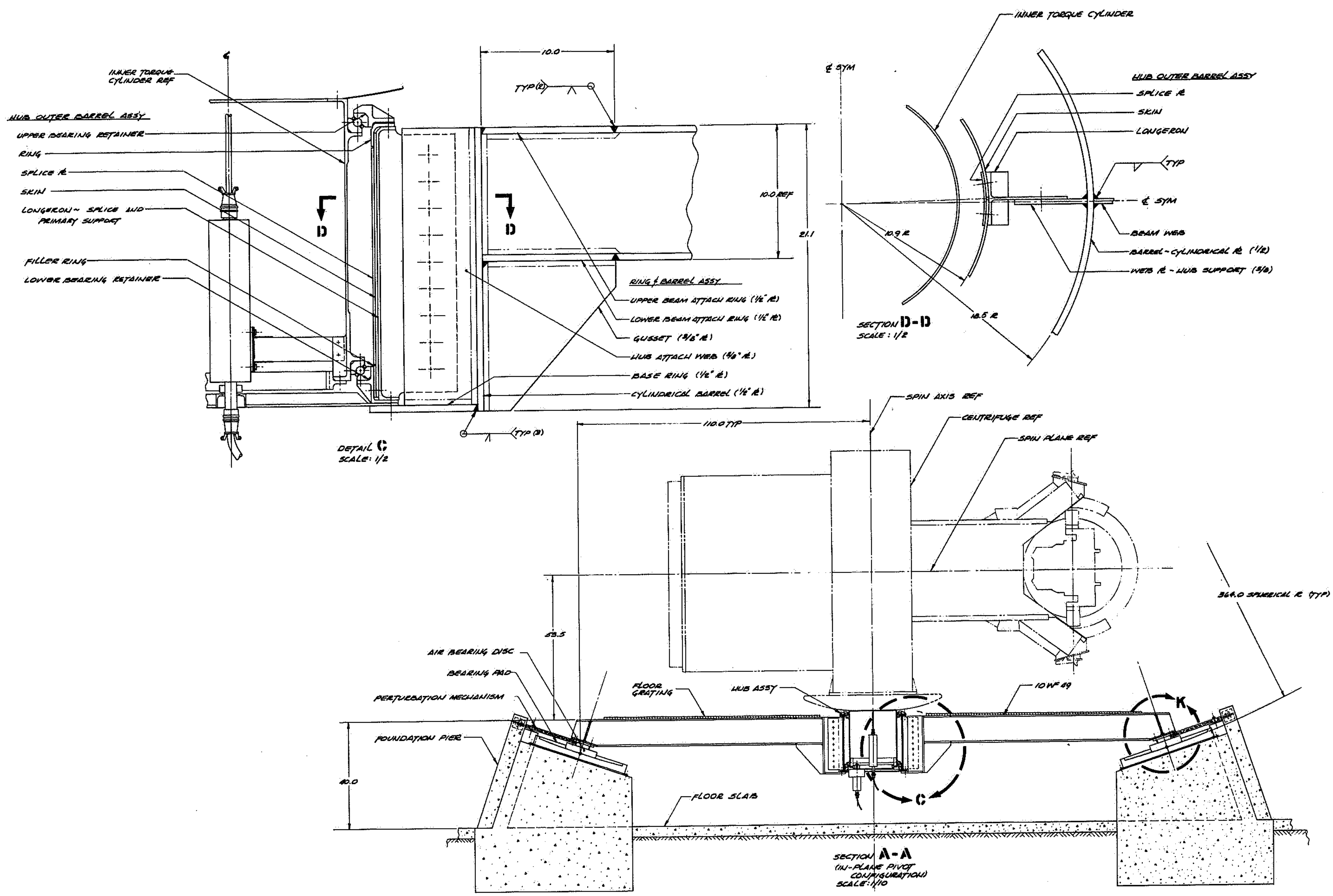
Drawing SRC-SD-110, 2. General Arrangement - Ground Based Prototype Space Research Centrifuge.



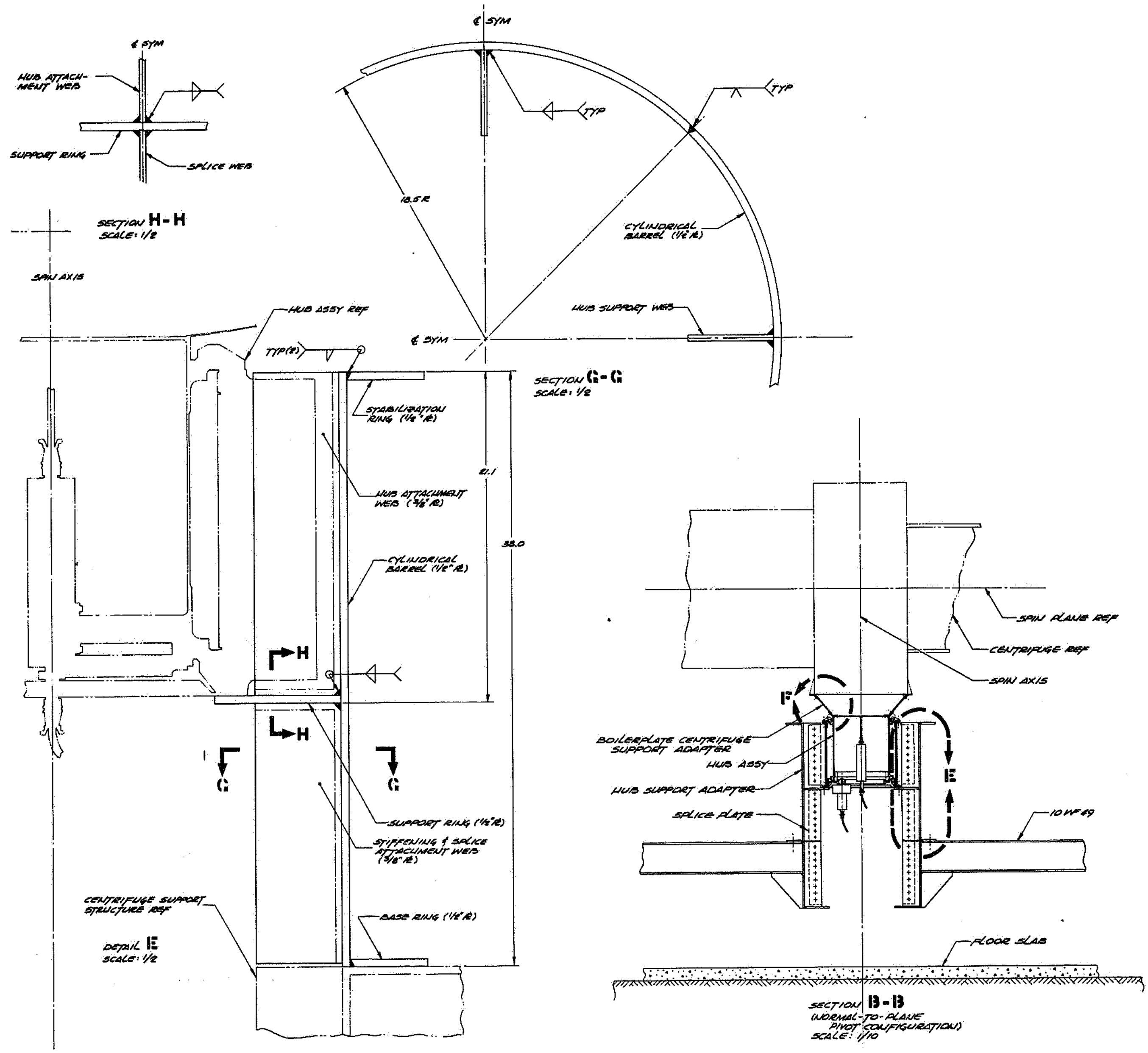
Drawing SRC-SD-110, 3. General Arrangement - Ground Based Prototype Space Research Centrifuge.



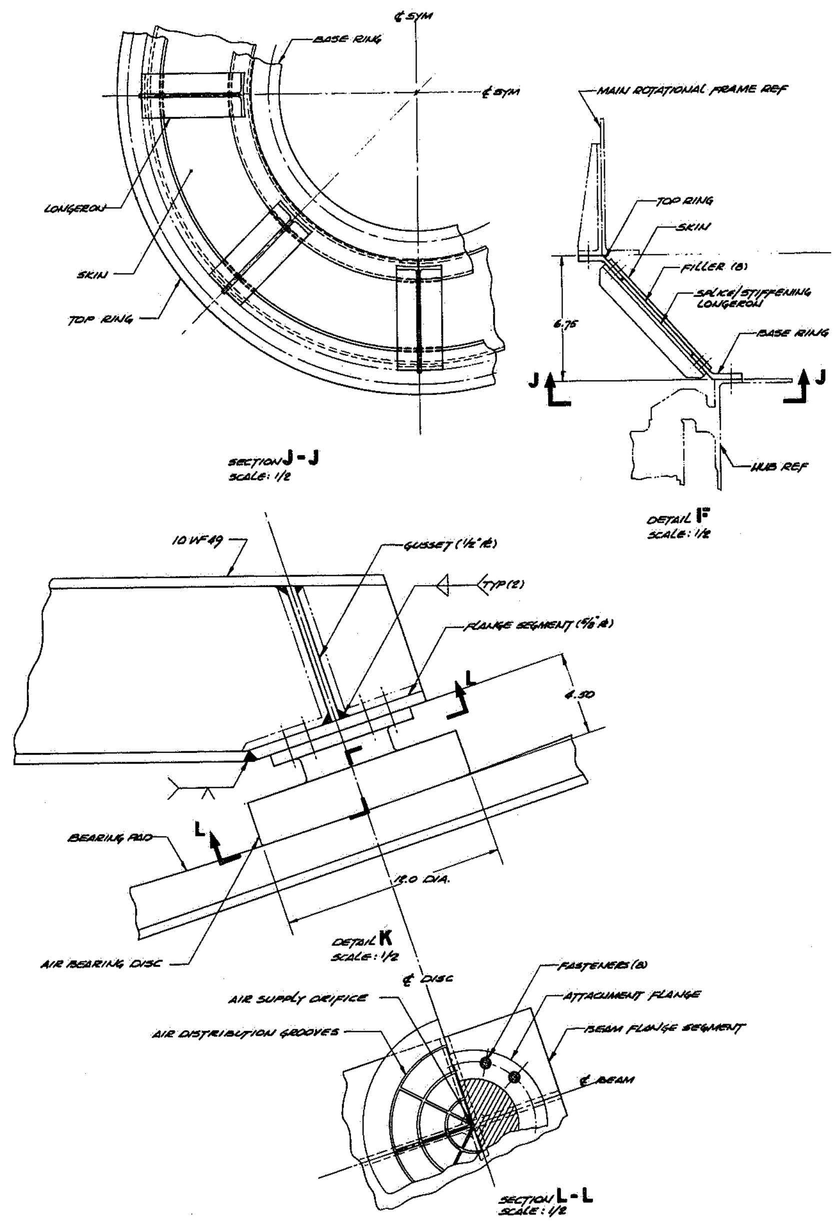
Drawing SRC-SD-109, 1. Support Structure, Sensor Hub Interface and Perturbation Mechanism - Ground Based Centrifuge.



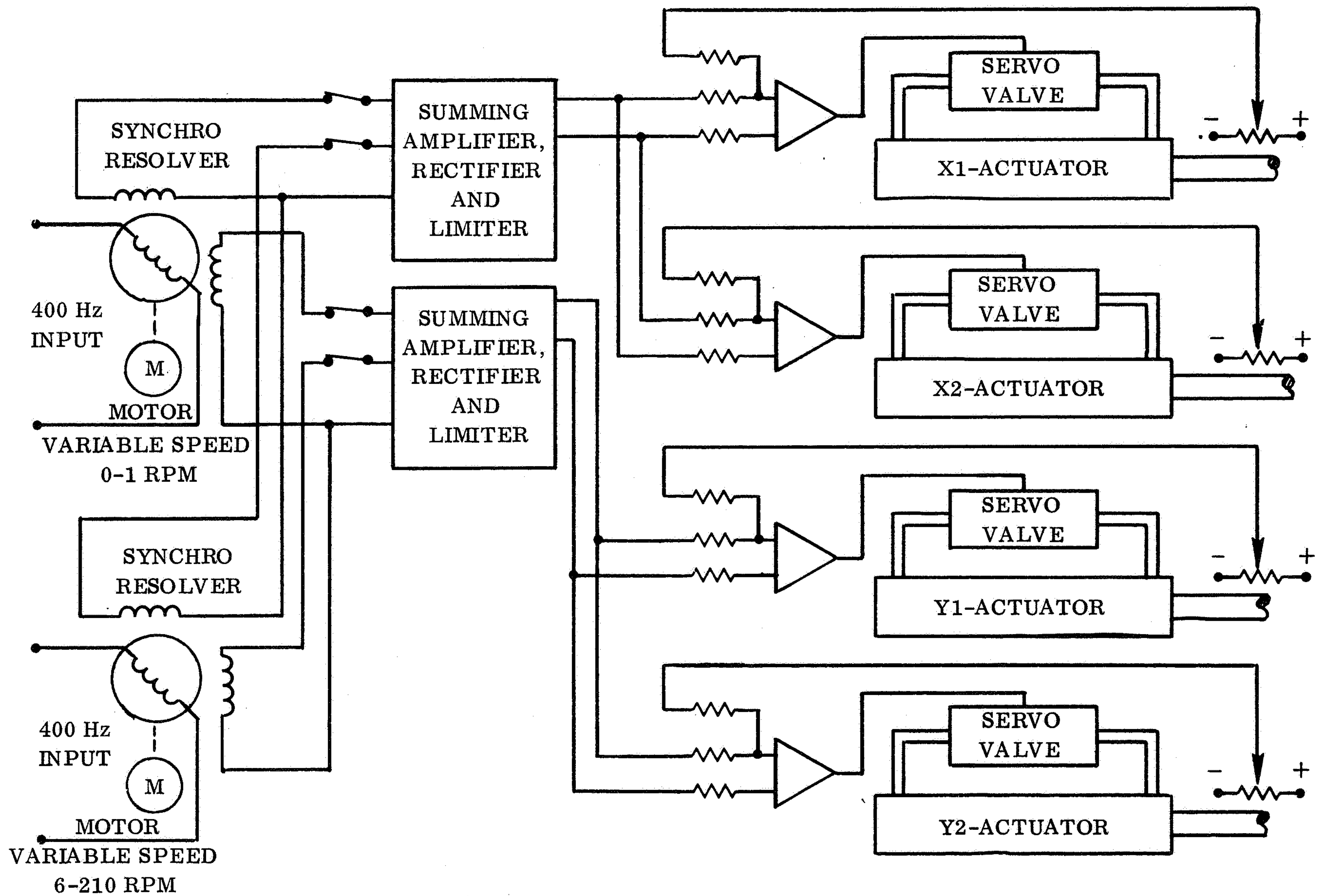
Drawing SRC-SD-109, 2. Support Structure, Sensor Hub Interface and Perturbation Mechanism - Ground Based Centrifuge.



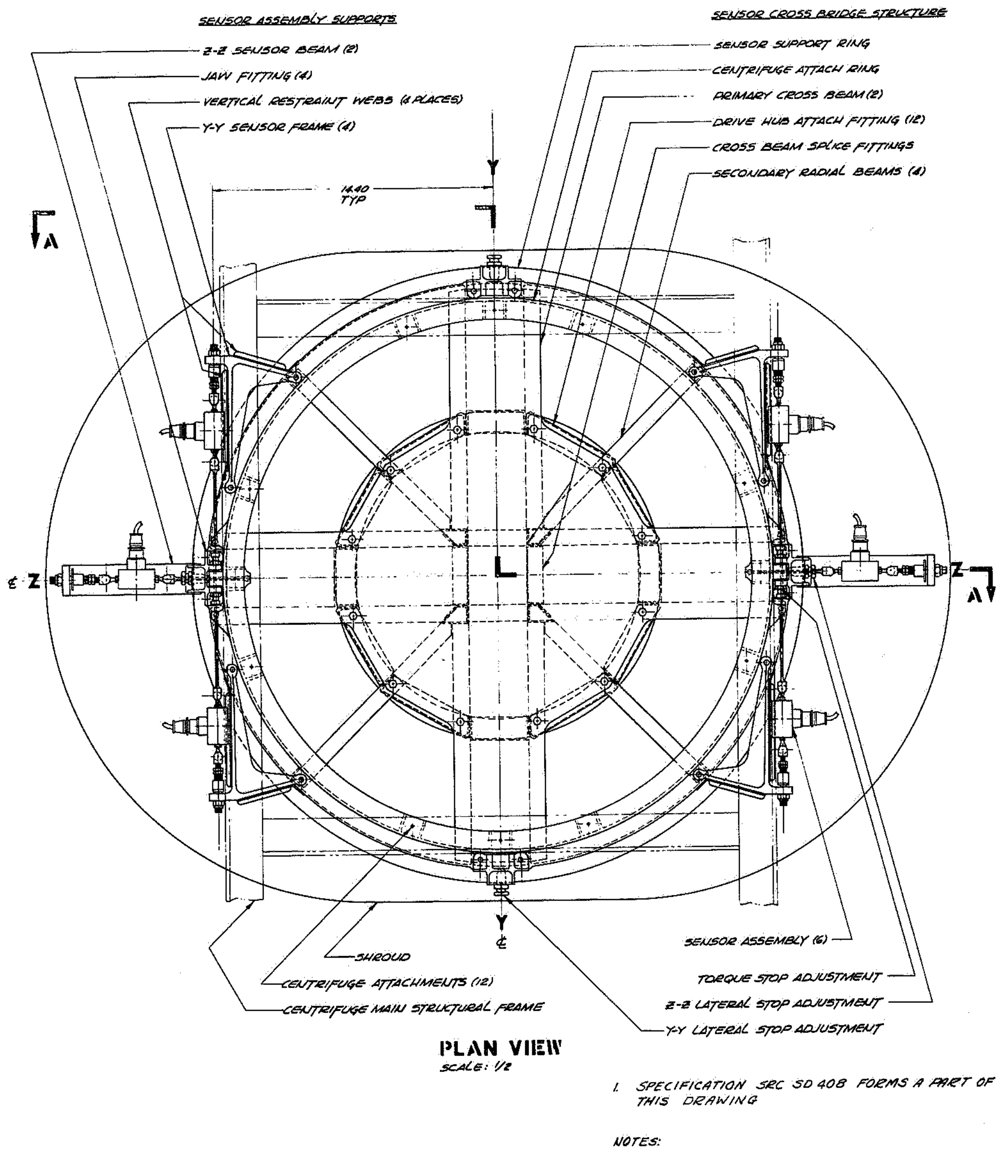
Drawing SRC-SD-109, 3. Support Structure, Sensor Hub Interface and Perturbation Mechanism - Ground Based Centrifuge.



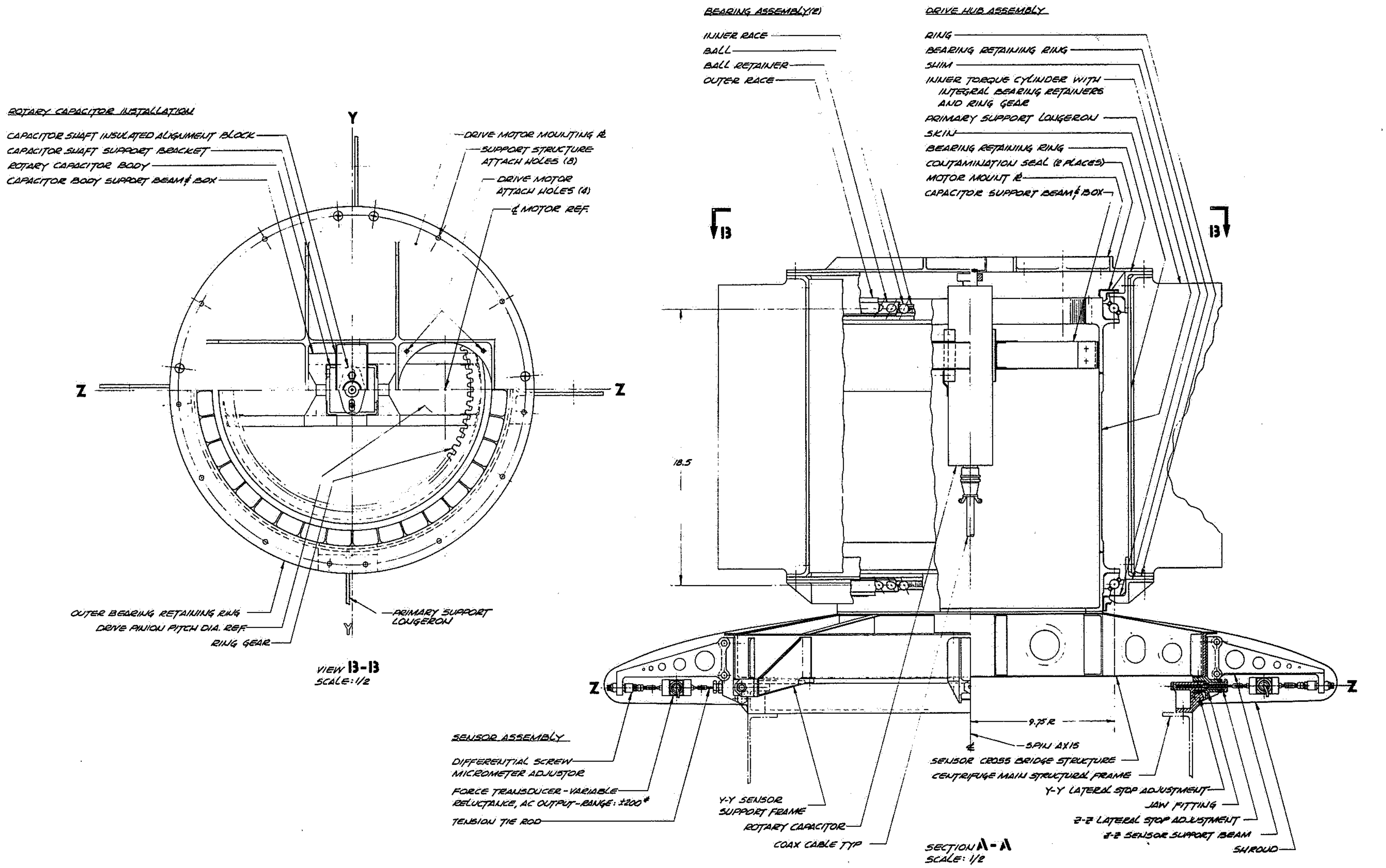
Drawing SRC-SD-109, 4. Support Structure, Sensor Hub Interface and Perturbation Mechanism - Ground Based Centrifuge.



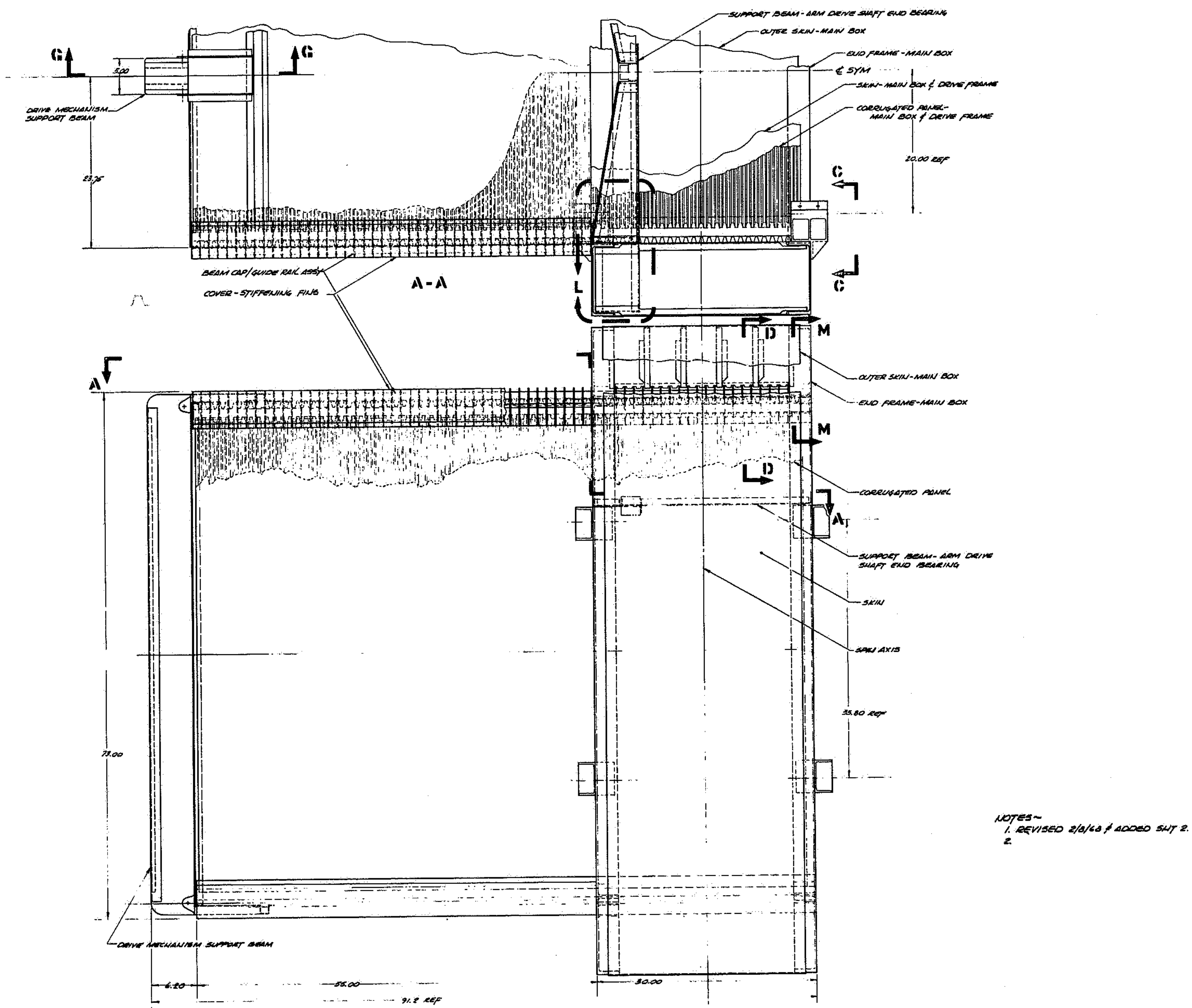
Drawing SRC-SC-109, 5. Support Structure, Sensor Hub Interface and Perturbation Mechanism - Ground Based Centrifuge.



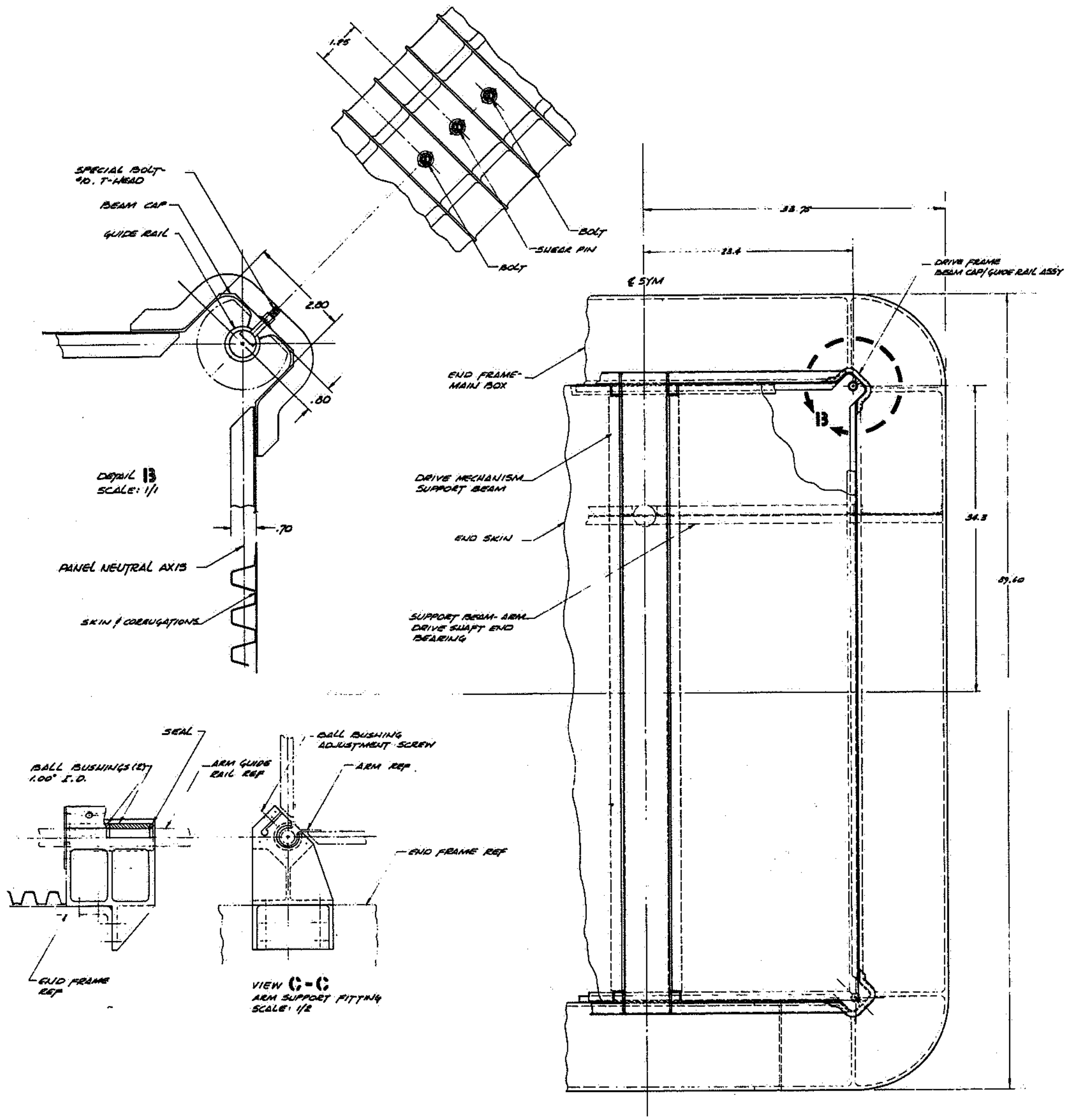
Drawing SRC-SD-407, 1. Drive Hub and Sensor System - Ground Based Centrifuge.



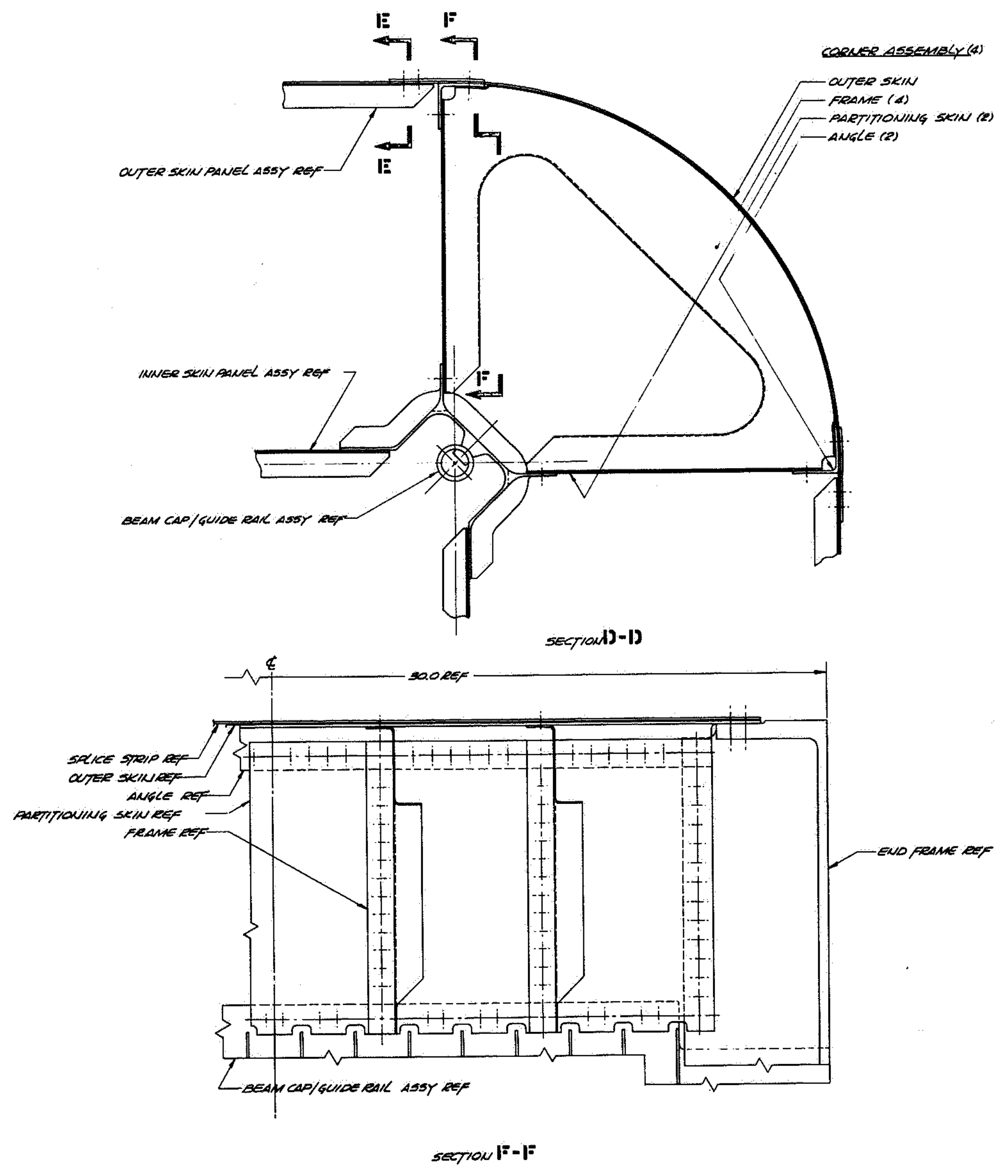
Drawing SRC-SD-407, 2. Drive Hub and Sensor System - Ground Based Centrifuge.



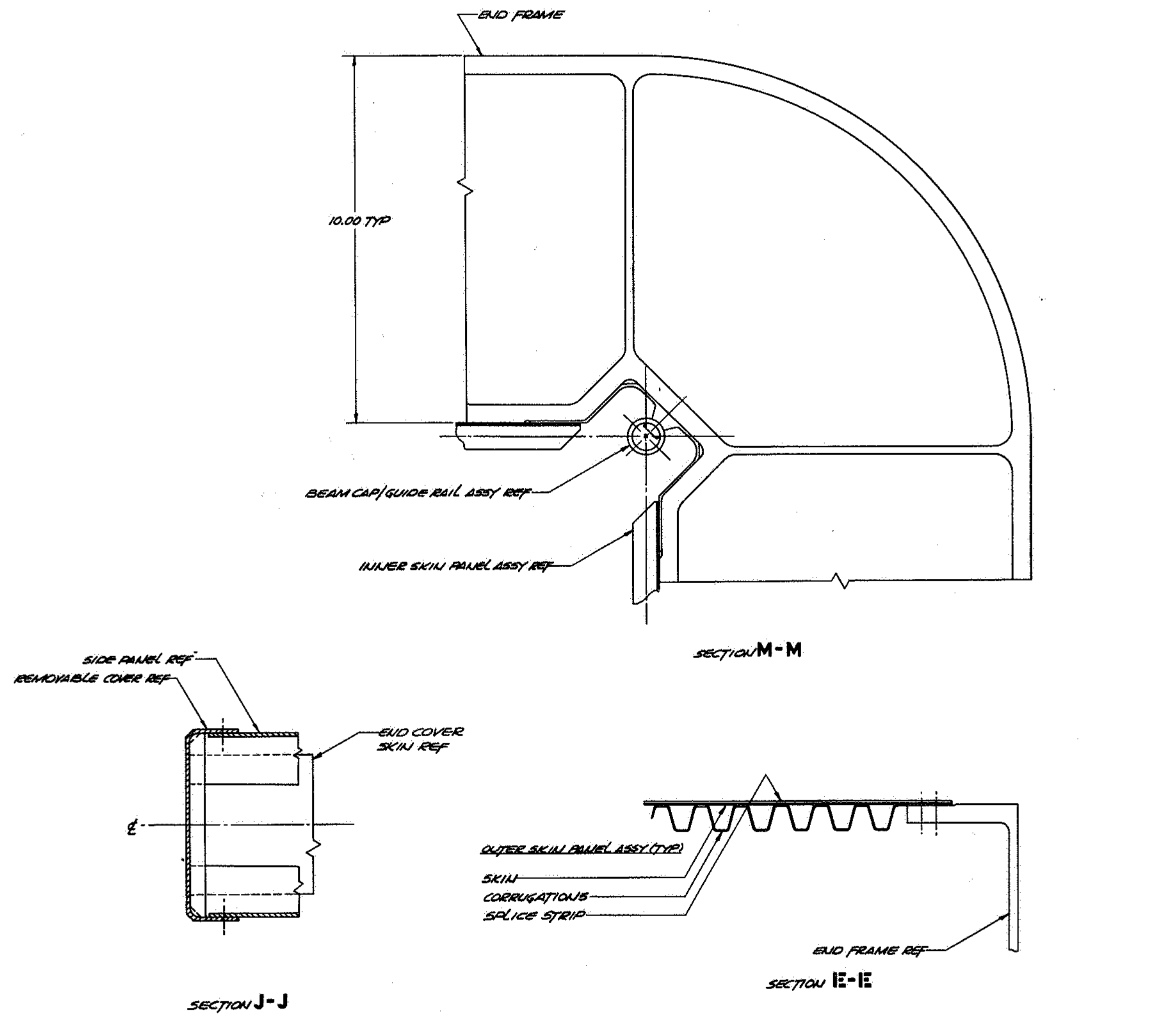
Drawing SRC-SD-403, 1. Main Rotational Frame and Arm/Counterweight Drive Frame Structural Assembly.



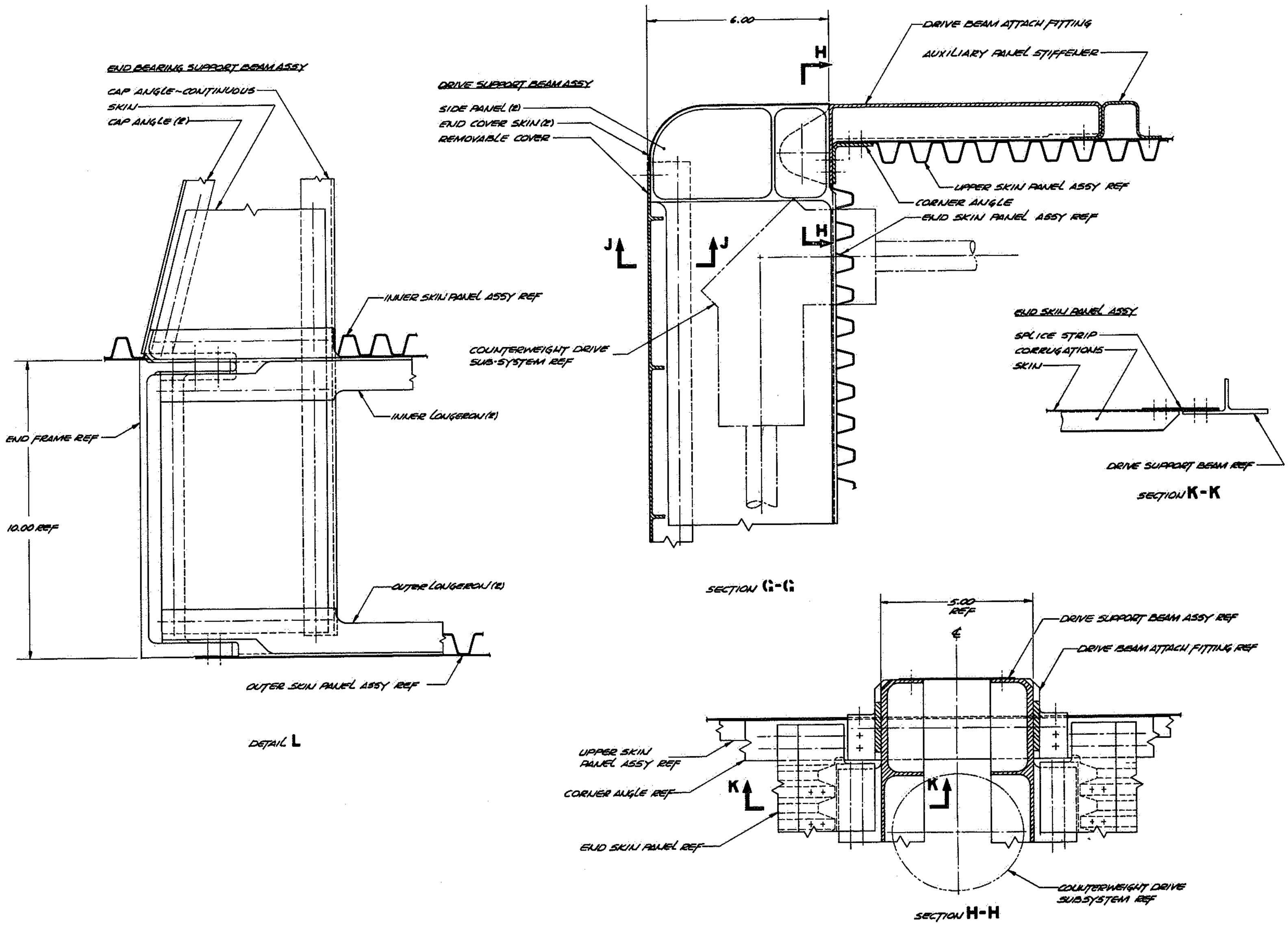
Drawing SRC-SD-403, 2. Main Rotational Frame and Arm/Counterweight Drive Frame Structural Assembly.



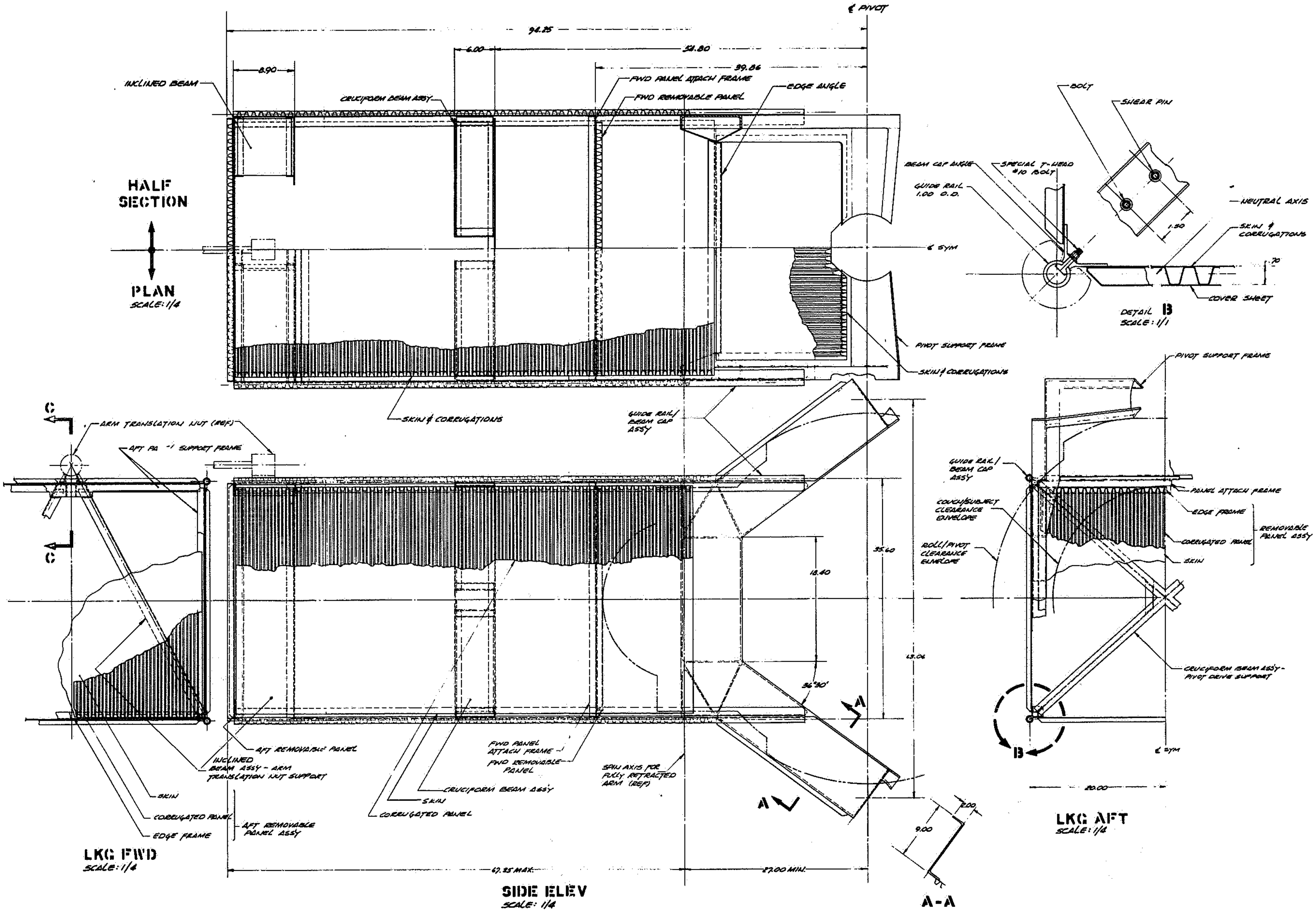
Drawing SRC-SD-403, 3. Main Rotational Frame and Arm/Counterweight Drive Frame Structural Assembly.



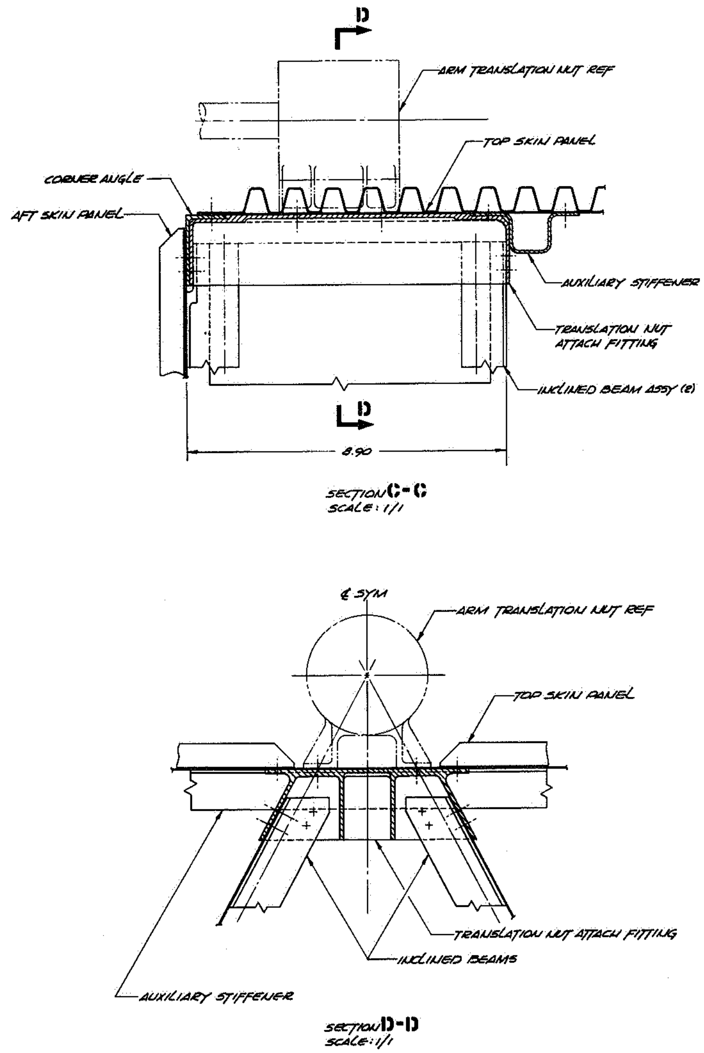
Drawing SRC-SD-403, 4. Main Rotational Frame and Arm/Counterweight Drive Frame Structural Assembly.



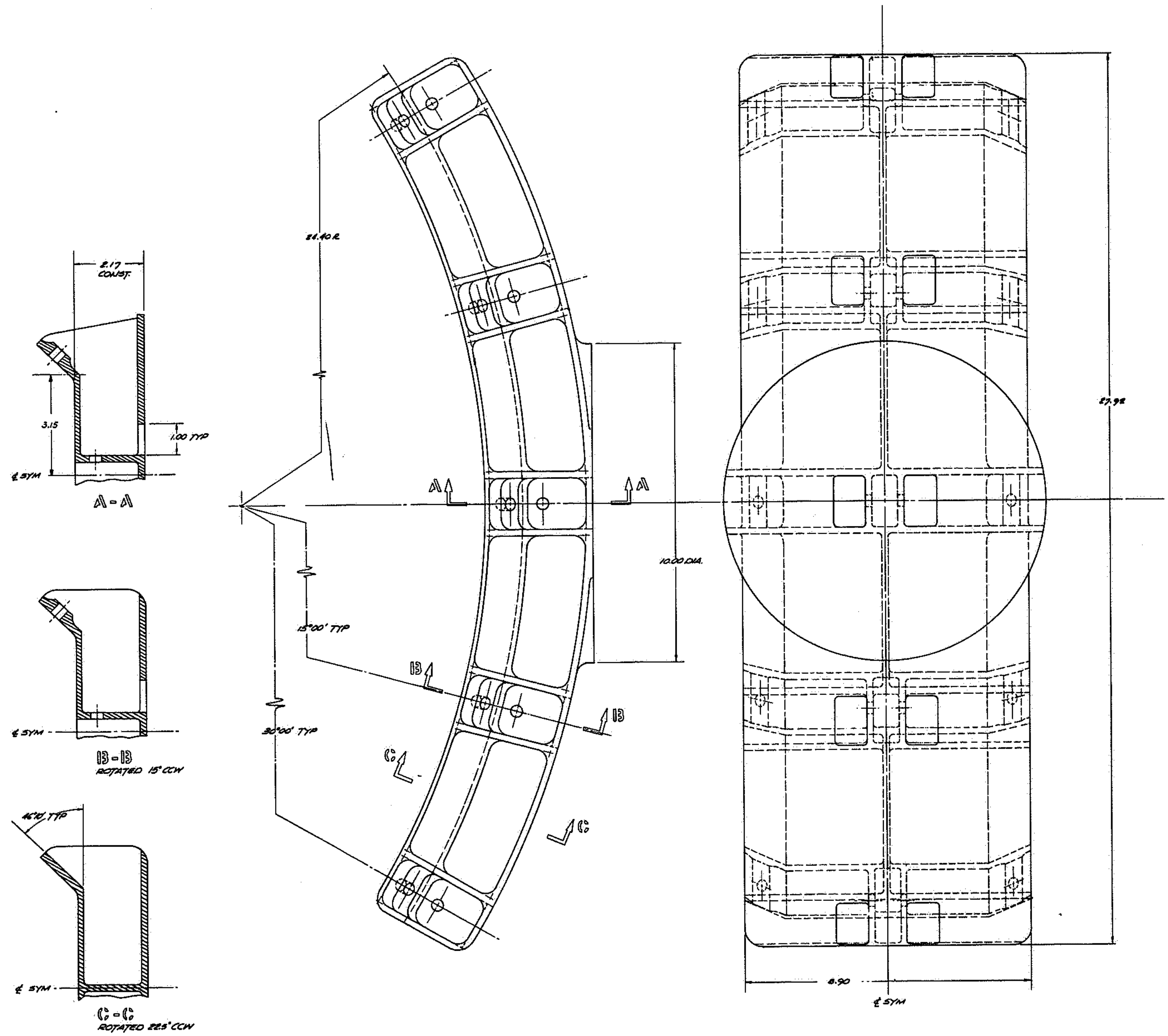
Drawing SRC-SD-403, 5. Main Rotational Frame and Arm/Counterweight Drive Frame Structural Assembly.



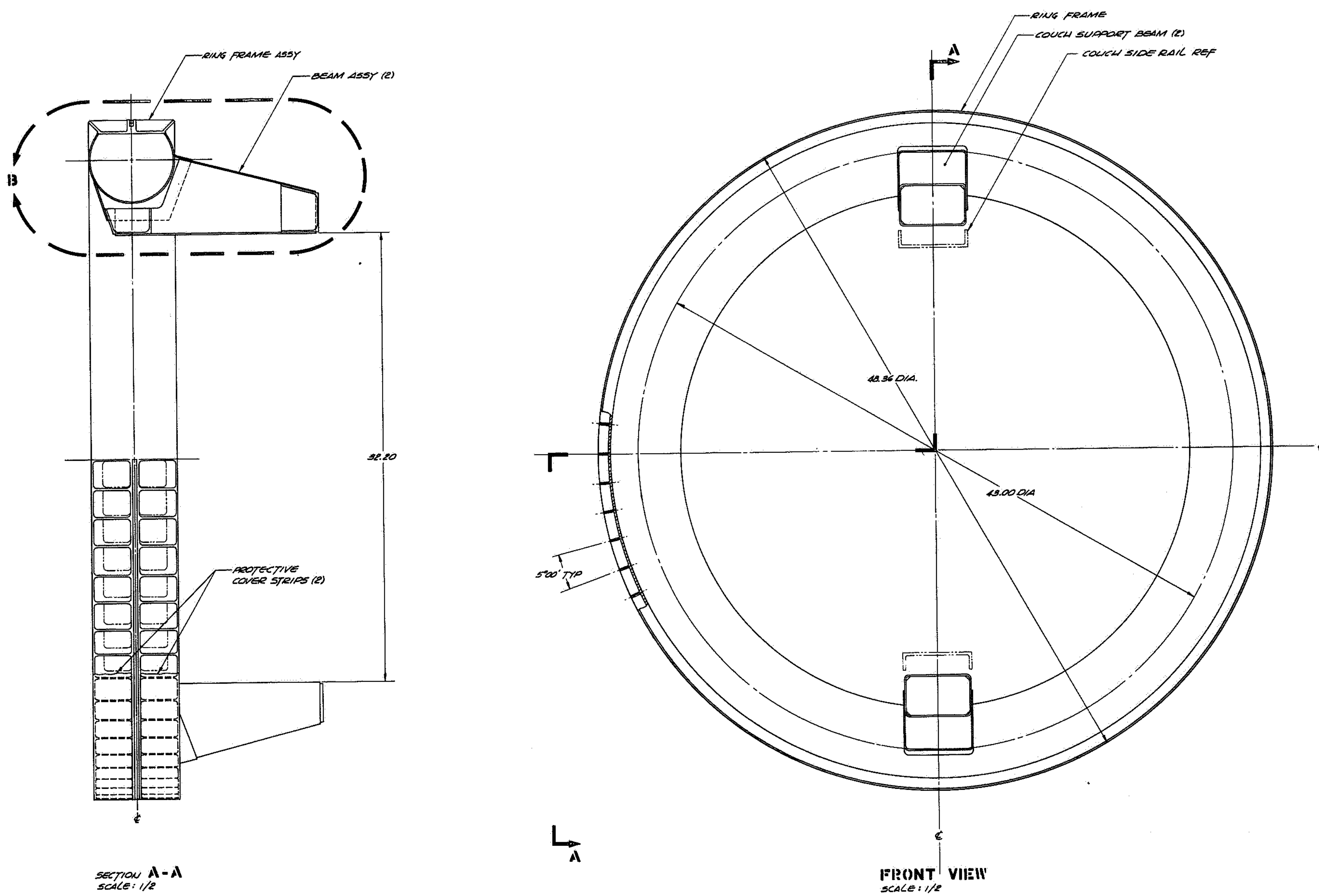
Drawing SRC-SD-402, 1. Radius Arm- Structural Assembly.



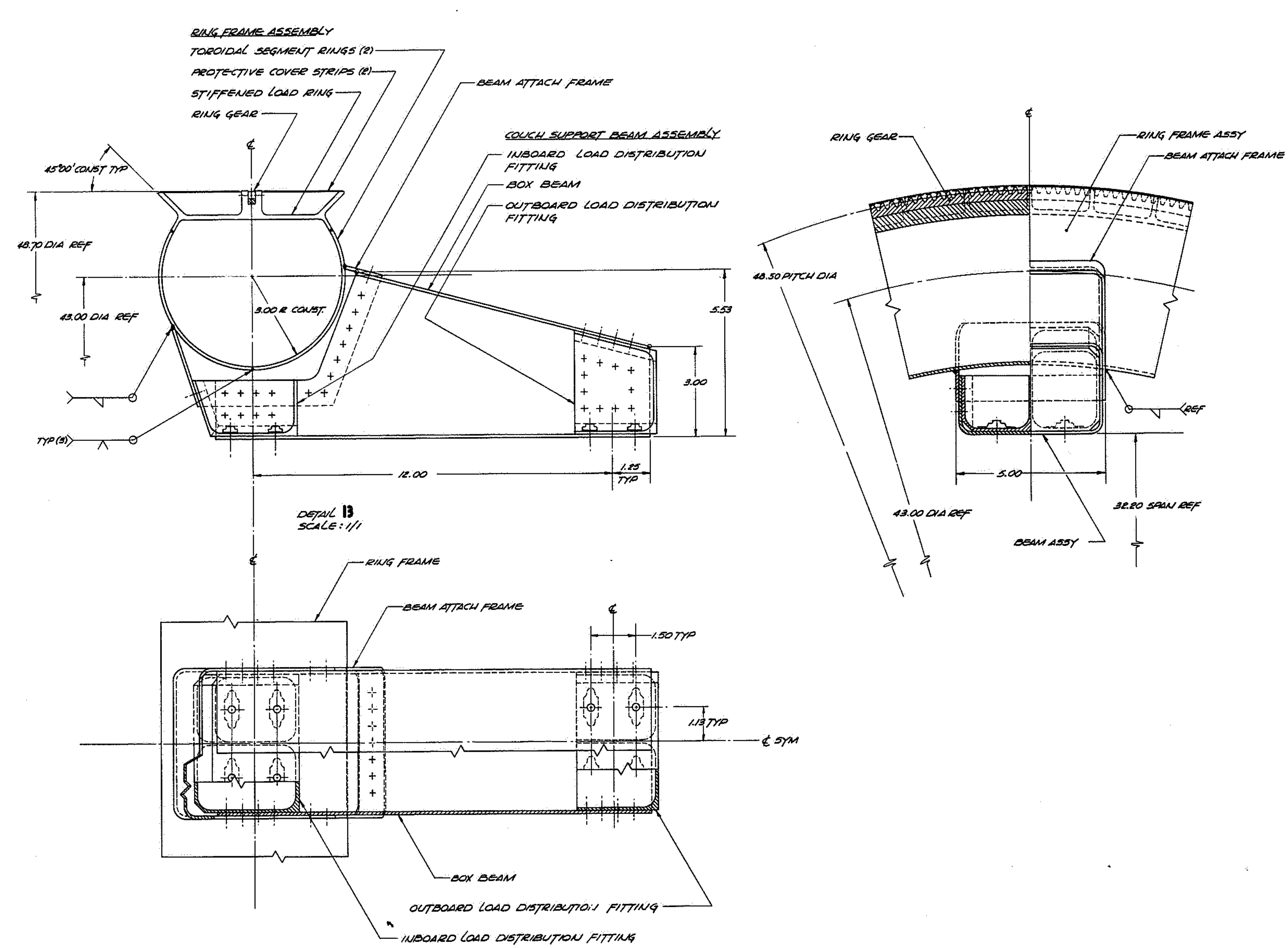
Drawing SRC-SD-402, 2. Radius Arm-Structural Assembly.



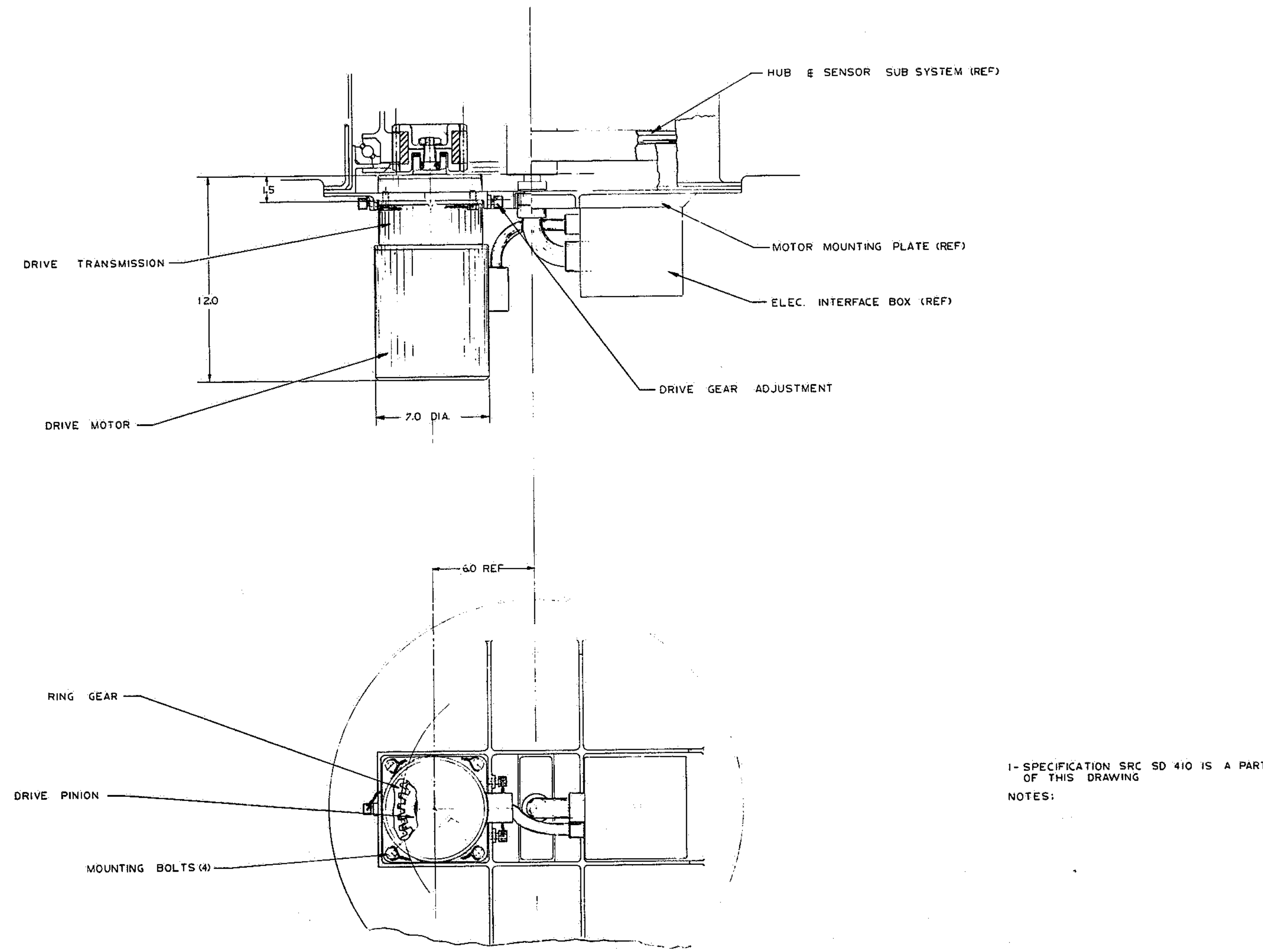
Drawing SRC-SD-405. Pivot Segment - Space Research Centrifuge.



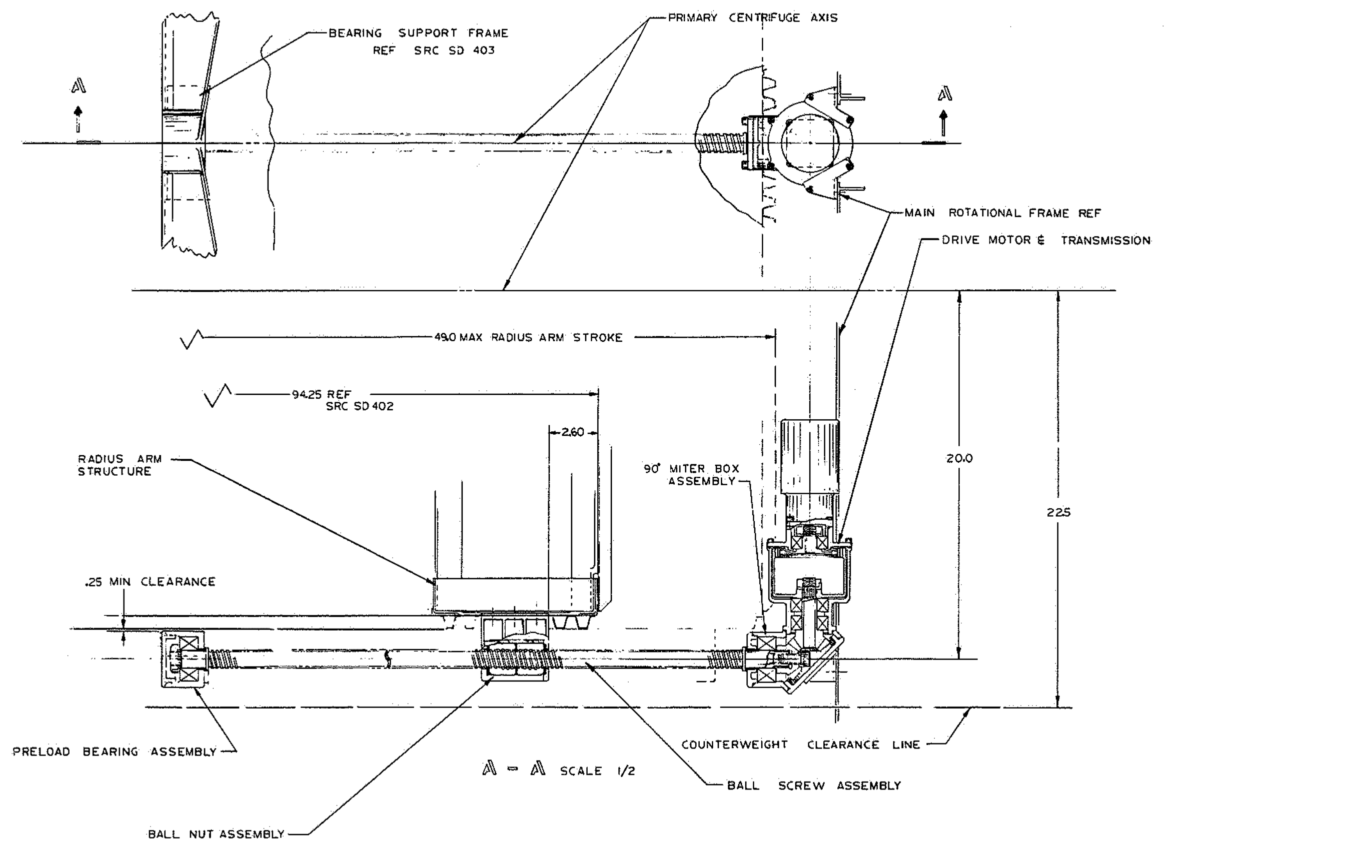
Drawing SRC-SD-514, 1. Roll Frame Assembly - Ground Based Centrifuge.



Drawing SRC-SD-514, 2. Roll Frame Assembly - Ground Based Centrifuge.

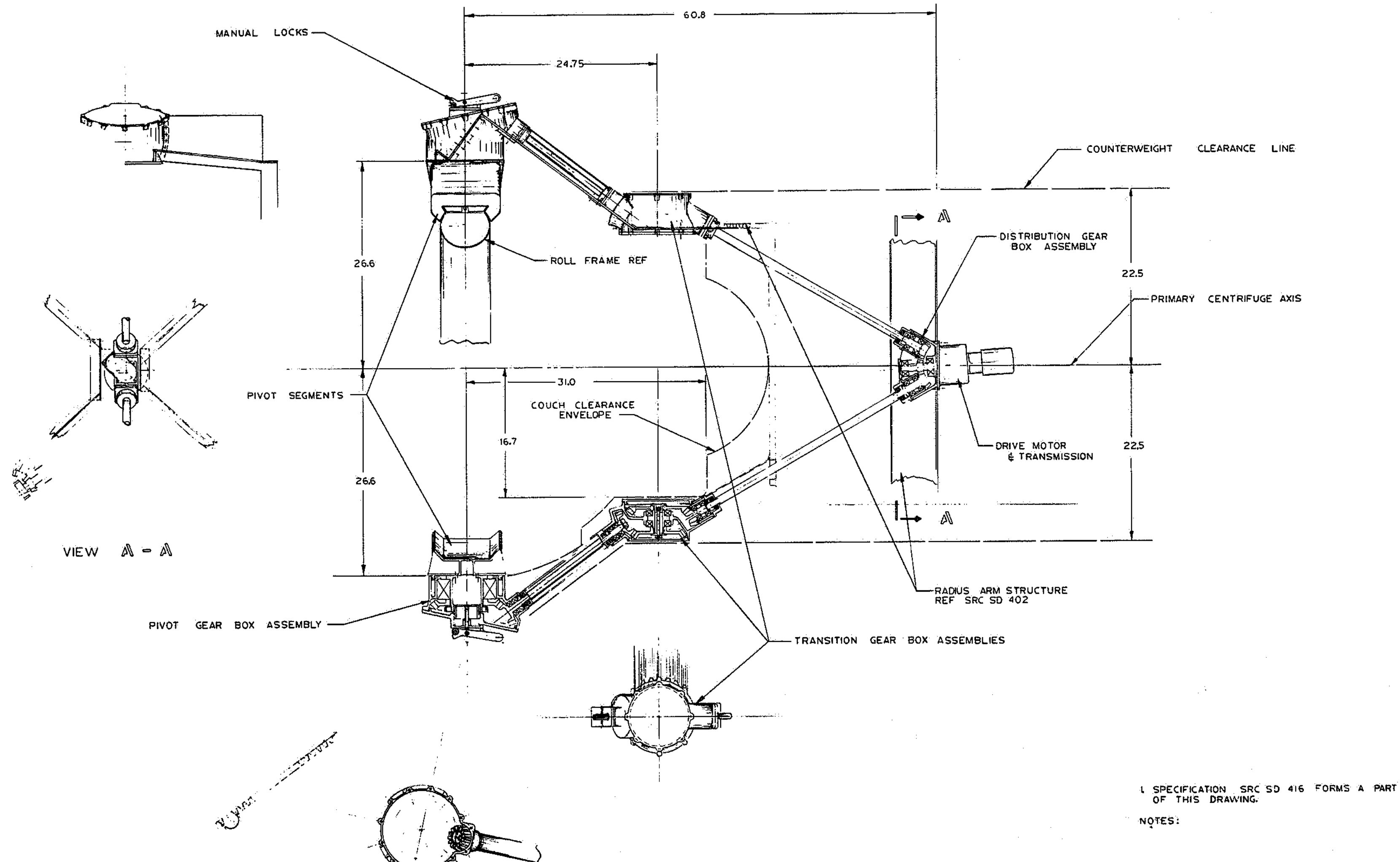


Drawing SRC-SD-409. Primary Drive Subsystem - Space Research Centrifuge.

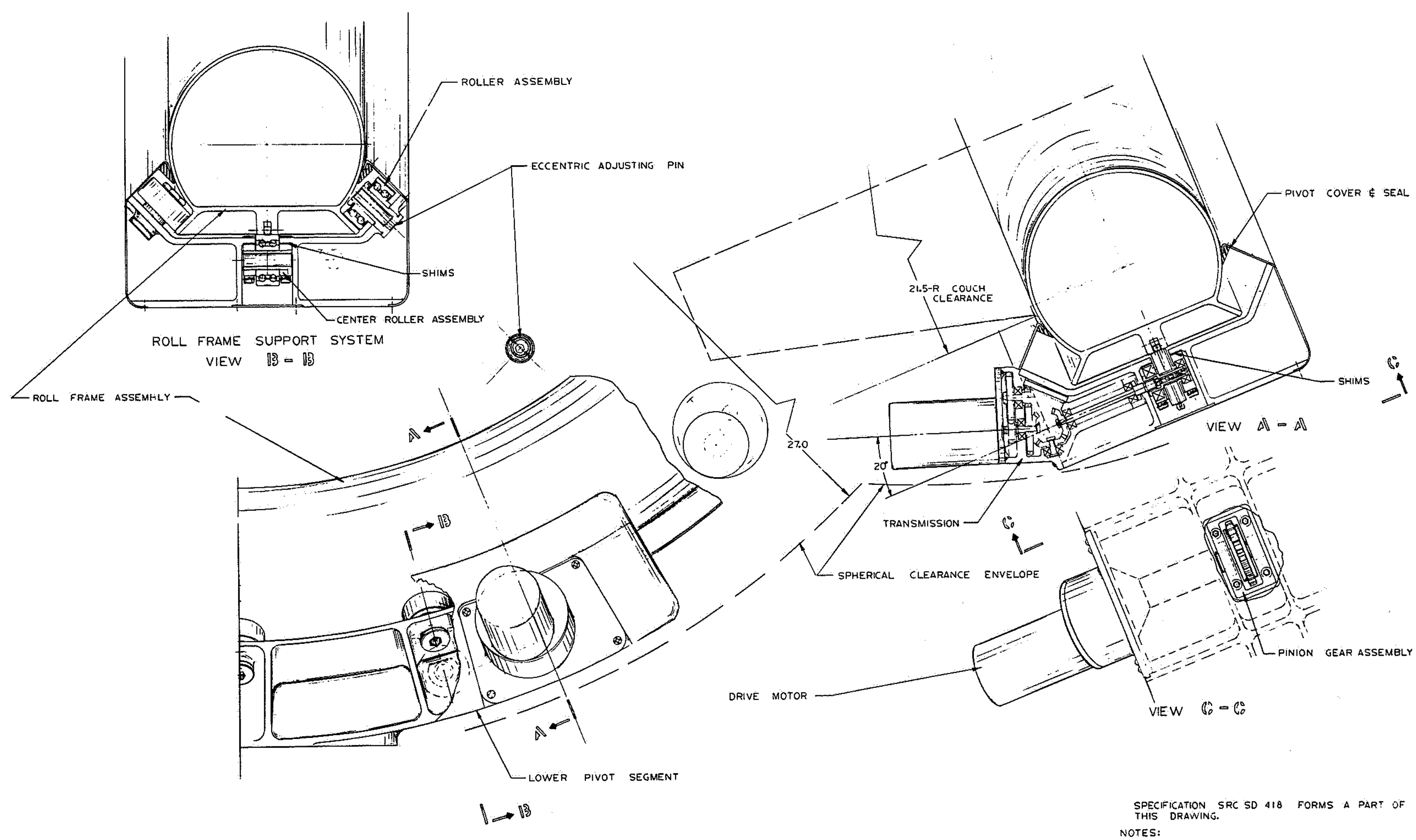


NOTES:
1. SPECIFICATION SRC SD 414 FORMS A PART OF THIS DRAWING.

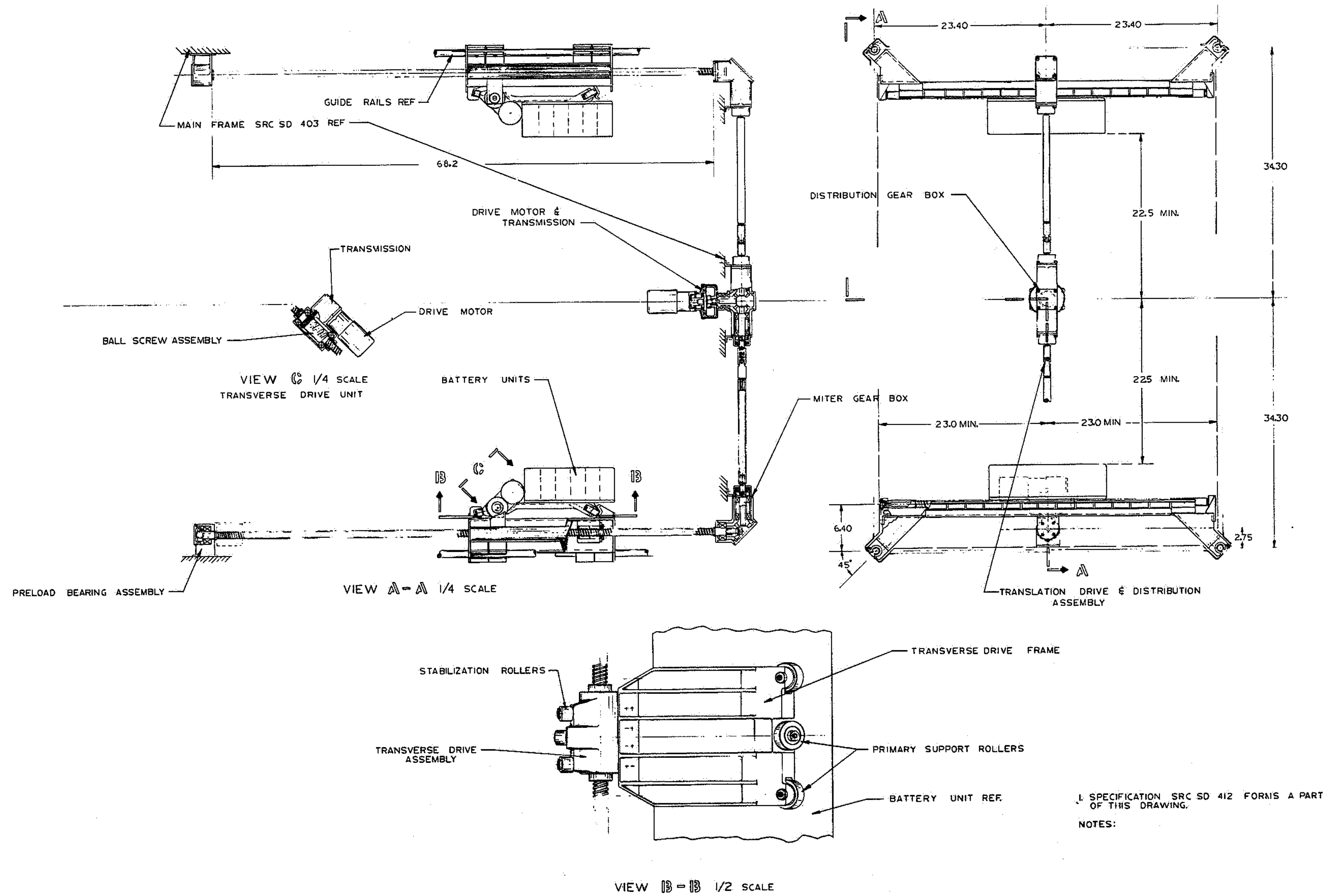
Drawing SRC-SD-413. Translation Drive Subsystem - Space Research Centrifuge.



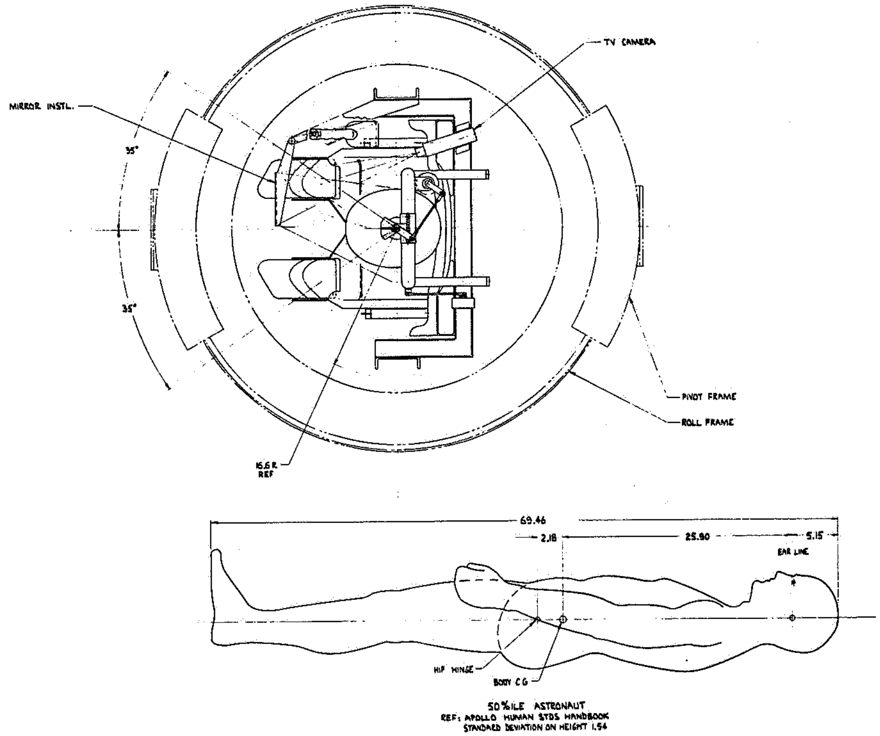
Drawing SRC-SD-415. Pivot Drive Subsystem - Space Research Centrifuge.



Drawing SRC-SD-417. Roll Drive Subsystem - Space Research Centrifuge.



Drawing SRC-SD-411. Counterbalance Subsystem - Space Research Centrifuge.



4. HEAD MOVEMENT POT DATA (Y&Z)

EXCURSION	± 35°
POSITION ACCURACY	± ½°
MAX RATE	225°/SEC
MIN RATE	90°/SEC
RATE ACCURACY	± 3°/SEC

ALTERNATE LEG POSITIONS CORRESPOND TO 30° INCREMENTS ABOUT HIP HINGE

3. TARGET WEIGHT BREAKDOWN (LB)

STRUCTURE	54
CUSHIONS & HARNESS	23
POWER & DISTRIBUTION	20
INST & COMMN	20
WASTE COLLECTION	50
	167

2. WASTE COLLECTION ARRANGEMENTS IN SADDLE AREA SUBJECT TO MOCKUP.

1. SPECIFICATION SRC SD 513 FORMS A PART OF THIS DRAWING

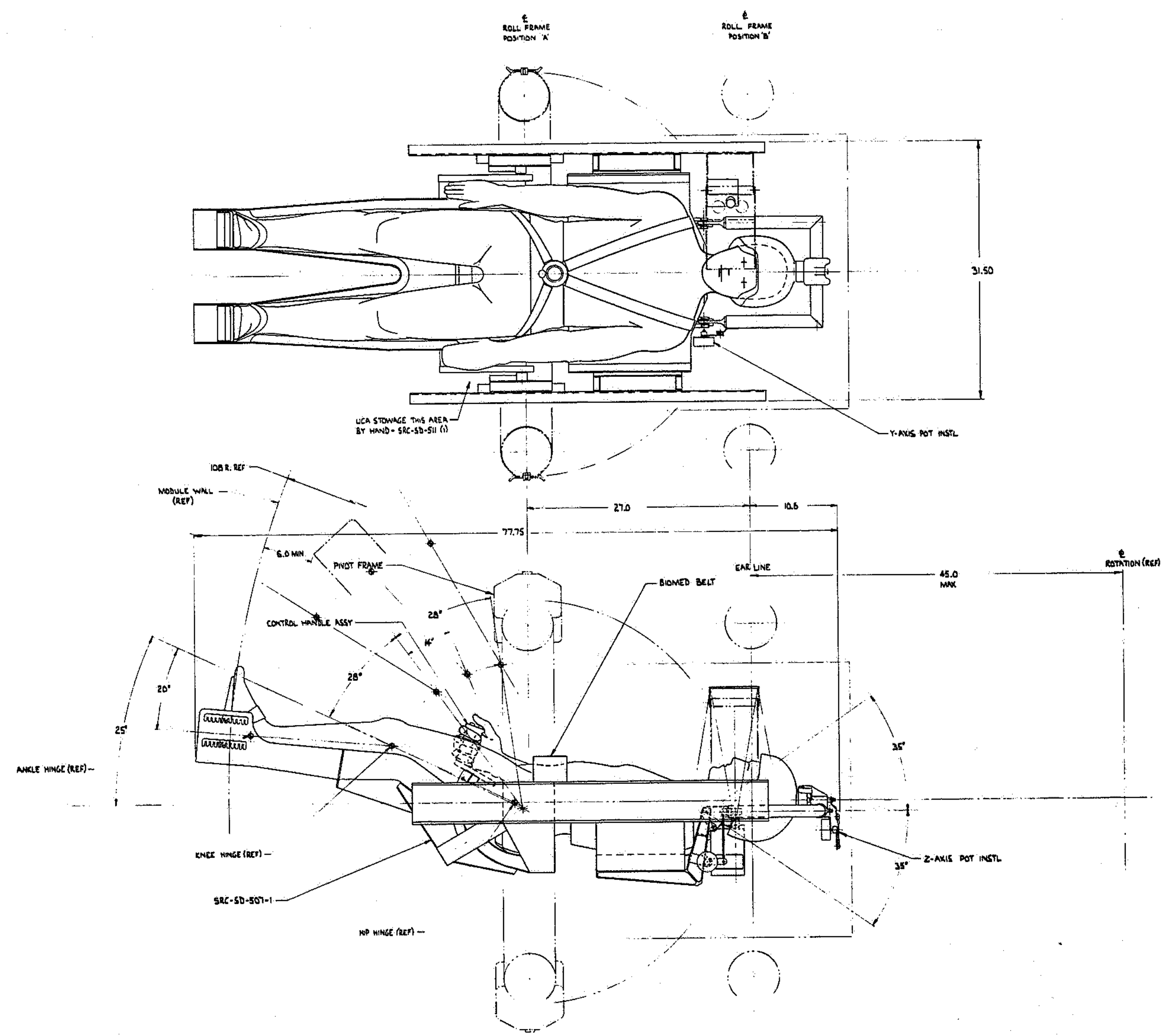
NOTES:

QTY	PART NO.	DESCRIPTION	WT.
REF	SRC-SD-512	ADAPTABILITY OF WEBER COUCH	—
1	SRC-SD-511	UCA ARRANGEMENT	
1	SRC-SD-	Z-AXIS HEAD MOVEMENT POT INSTL.	
1	SRC-SD-	Y-AXIS HEAD MOVEMENT POT INSTL.	
1	SRC-SD-	TV CAMERA, MIRROR & MOUNTS	
1	SRC-SD-	BIOMED BELT	
1	SRC-SD-	CONTROL HANDLE ASSY	
1	SRC-SD-	HARNESS	
1	SRC-SD-507-1	COUCH STRUCTURE	49.8

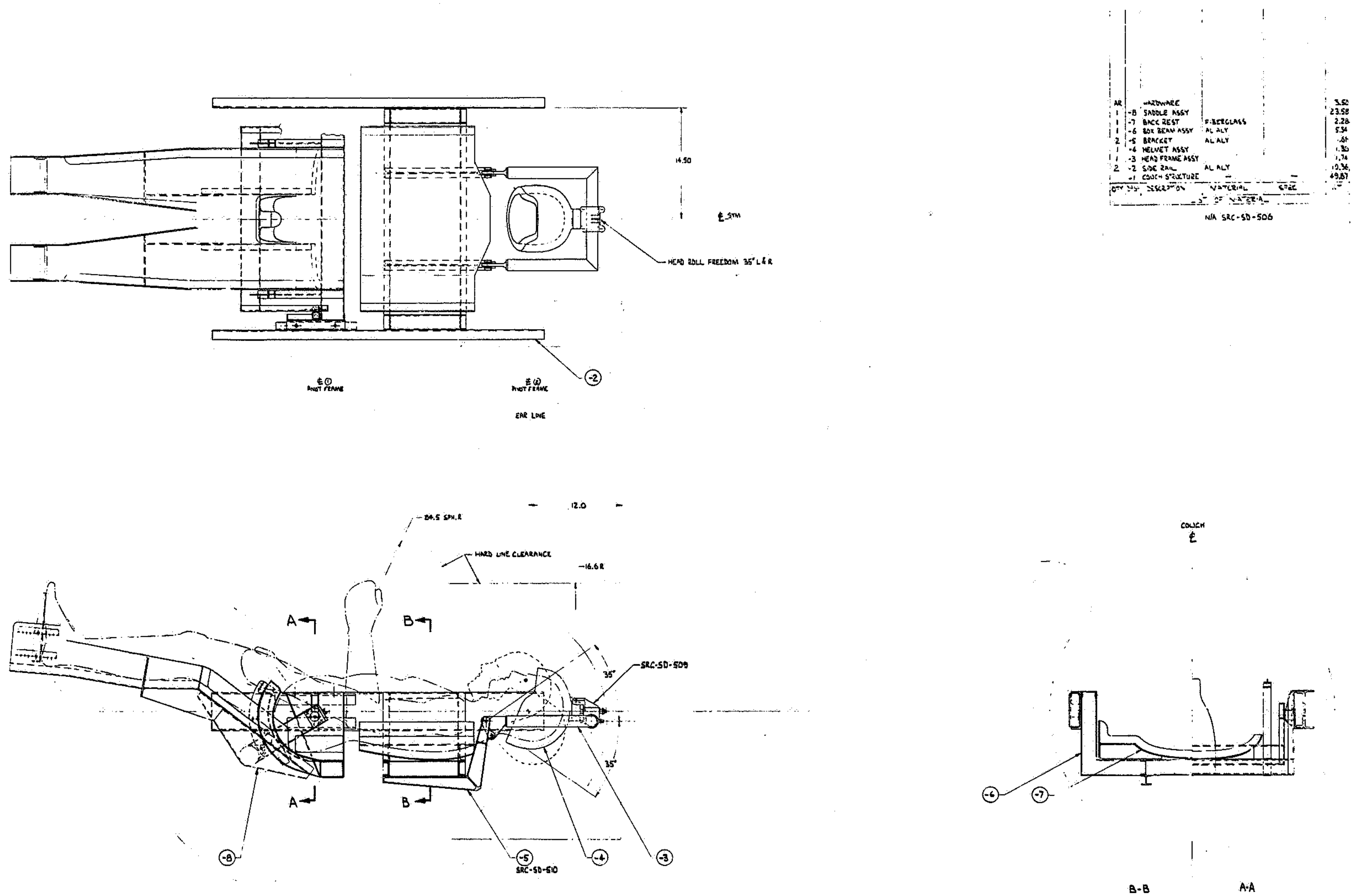
LIST OF MATERIAL

N/A SRC-SD-(TOP)

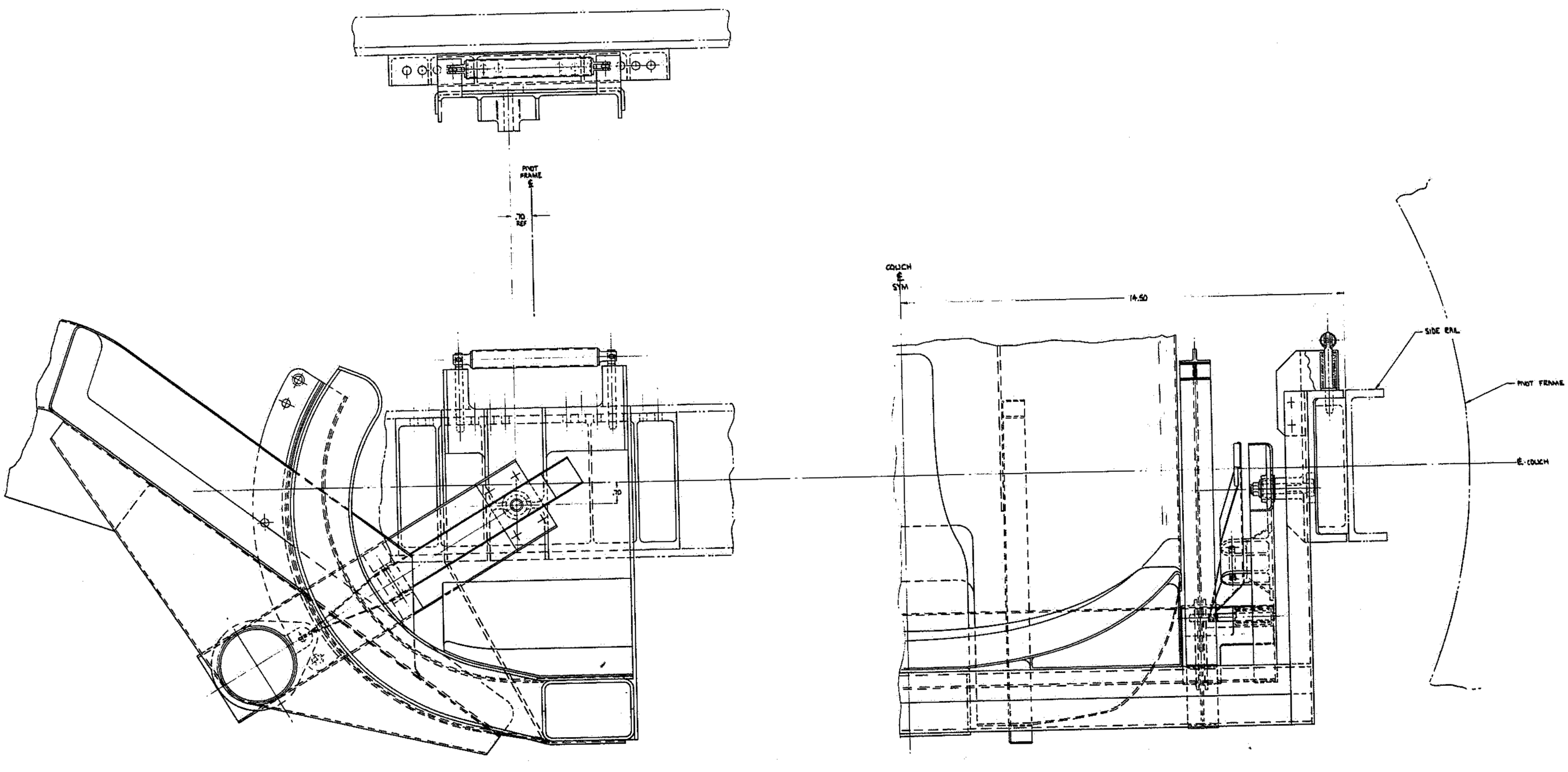
Drawing SRC-SD-506, 1. Couch Assembly - Space Research Centrifuge.



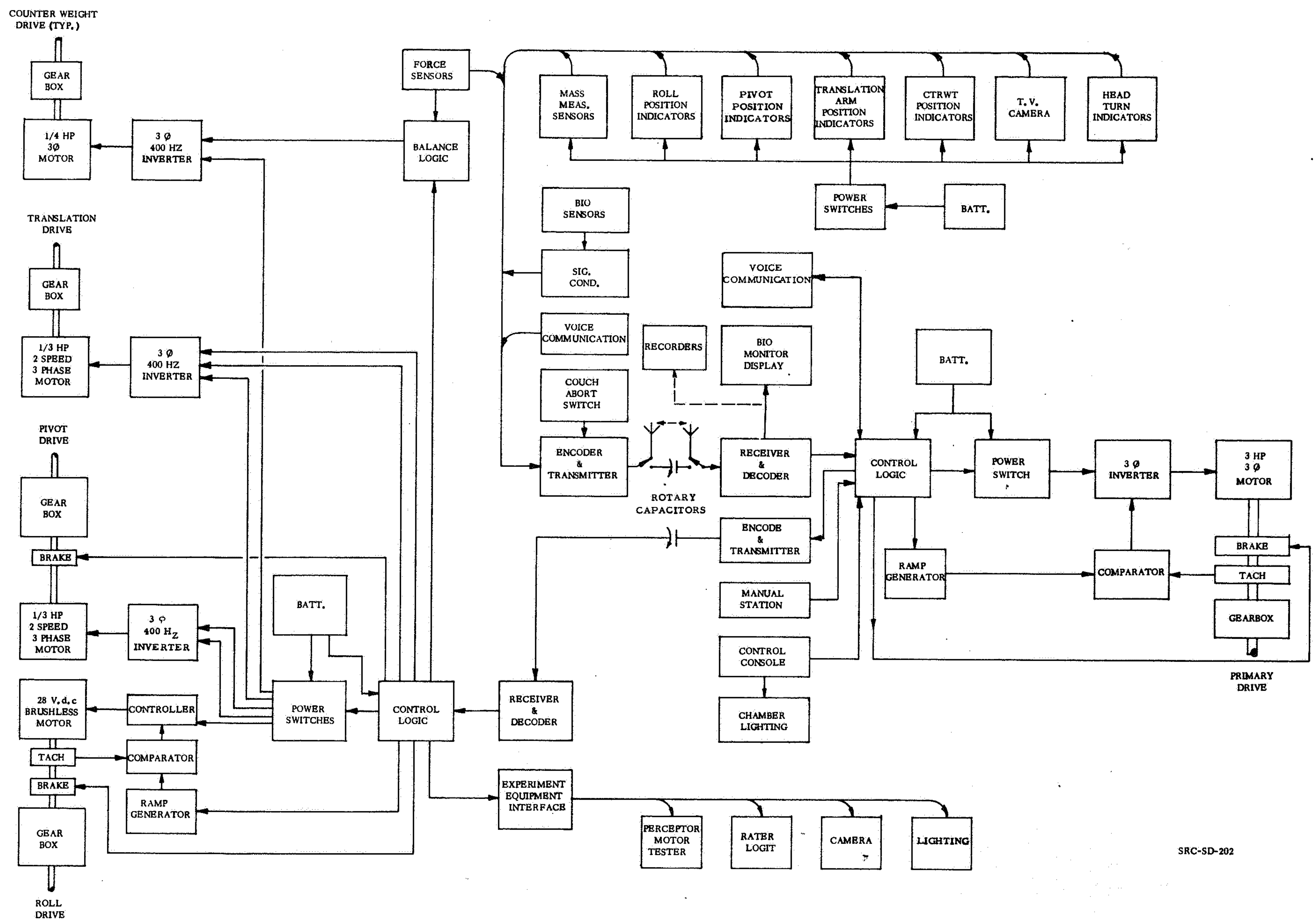
Drawing SRC-SD-506, 2. Couch Assembly - Space Research Centrifuge.



Drawing SRC-SD-507. Structural Arrangement - Couch, Space Research Centrifuge.



Drawing SRC-SD-508. Saddle and Adjustment - Couch, Space Research Centrifuge.



Drawing SRC-SD-202 Command and Control Space Research Centrifuge

ABSTRACT

This document is a portion of the final report prepared under Contract NAS 1-7309, Feasibility Study of a Centrifuge Experiment for the Apollo Applications Program. The contract was performed for the Langley Research Center, National Aeronautics and Space Administration, Hampton, Virginia. The complete final report consists of the following documents:

NASA CR-66649 GDC-DCL-68-001 (SRC-AN-703)	Volume I	Space Research Centrifuge Configuration, Installation and Feasibility Studies
NASA CR-66650 GDC-DCL-68-002 (SRC-SD-604)	Volume II	Specification and Test Requirements - Space Research Centrifuge Engineering Development Prototype
NASA CR-66651 GDC-DCL-68-003 (SRC-MS-112)	Volume III	Experimental Requirements for the Space Research Centrifuge
GDC-DCL-68-004 (SRC-MS-302)	Volume IV	Manned Centrifuge Test Report

This study examines the application of an on-board centrifuge as a versatile research tool for the measurement of human physiological responses in the space environment. A realistic orbital centrifuge is configured based on a specified series of experiments dealing primarily with vestibular and cardiovascular physiology. Experiment feasibility is established in terms of spacecraft stability, reliability, safety, economics, weight, power and other influential factors. A ground based prototype of the orbital machine is defined and the required test program outlined. The effects of cross-coupled angular accelerations induced by the interaction of the astronaut/machine/vehicle motions is examined by a series of ground centrifuge tests with human subjects.